

ISSN :3107-4200



SABUJEEMA AGRI NEWSLETTER

TRANSFORMING AGRICULTURE

VOLUME 3, ISSUE 3

JUNE, 2026-AUGUST, 2026

An International Newsletter for Agriculture and Allied Sciences

www.sabujeema.in



Published by

Society for Agriculture, Allied Sciences and Technology

(Regd under the society regd Act XXI of 1860)

www.saast.co.in





Role of Bioinformatics in Agriculture: A New Hope for Farmers

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Agriculture forms the backbone of India, with farmers playing a crucial role in ensuring national food security. The agricultural sector currently faces significant challenges, including climate change, pest infestations, plant diseases, declining soil quality, and water scarcity. Advances in modern science are addressing these issues, with bioinformatics emerging as a key technology. Bioinformatics involves the application of computational tools to analyze biological data viz., genes, proteins, and DNA. This approach enables scientists to gain deeper insights into plants and microorganisms, facilitating the development of improved crop varieties. This article examines the role of bioinformatics in agriculture and outlines its potential benefits for farmers..

Introduction

Agriculture has undergone substantial transformation over the years. Historically, farmers relied primarily on traditional knowledge and experience. In the present era, modern technologies have enhanced the efficiency and sustainability of crop production. Among these advancements, bioinformatics integrates biology, computer science, and information technology to support agricultural innovation.

Although farmers may not use bioinformatics directly, the improved seeds, disease-resistant crops, and better farming practices they receive are often developed with the help of bioinformatics. This technology saves time, reduces the cost of research, and helps scientists to develop better solutions for agriculture.



Applications of Bioinformatics in Agriculture

Development of Improved Crop Varieties

Scientists use bioinformatics to study the genes of crops such as rice, wheat, maize, and pulses. By identifying useful genes, they can develop crop varieties that produce higher yields, tolerate drought, survive floods, and resist diseases.

Disease and Pest Management

Crop diseases and insect pests cause heavy losses every year. Bioinformatics helps scientists identify the disease-causing organisms quickly and understand how they spread. This information supports the development of resistant crop varieties and better disease management strategies, reducing crop losses.

Climate-Resilient Agriculture

Changing weather patterns affect crop production. Bioinformatics helps researchers identify genes associated with drought tolerance, heat resistance, and flood survival. These discoveries support the development of climate-resilient crops that can perform better under difficult environmental conditions.

Improving Soil Health

Healthy soil is essential for good crop production. Scientists study beneficial soil microorganisms using bioinformatics to understand how they improve soil fertility, increase nutrient availability, and support plant growth. This knowledge encourages sustainable farming with reduced dependence on chemical fertilizers.

Better Use of Water and Fertilizers

Bioinformatics contributes to the development of crop varieties that use water and nutrients more efficiently. Such crops require fewer resources while maintaining good yields, helping farmers save money and conserve natural resources.

Protection of Traditional Crop Varieties

India has many traditional crop varieties with valuable traits such as disease resistance and stress tolerance. Bioinformatics helps scientists study and conserve these genetic resources so they can be used for future crop improvement.



Supporting Plant Breeding

Plant breeders need to select the best parent plants for developing improved varieties. Bioinformatics allows researchers to analyze thousands of genes quickly, making the breeding process faster and more accurate than traditional methods alone.

Benefits to Farmers

The benefits of bioinformatics reach farmers through improved agricultural technologies. These include:

- High-yielding crop varieties.
- Disease- and pest-resistant crops.
- Better tolerance to drought, heat, and floods.
- Reduced use of pesticides and fertilizers.
- Improved crop quality and market value.
- Lower production costs and increased farm income.
- More sustainable farming practices.

Future Scope

The future of agriculture will increasingly depend on digital technologies. Bioinformatics, together with artificial intelligence, genomics, and precision agriculture, will help scientists develop crops that can meet future food demands while protecting natural resources. As research continues, farmers will benefit from improved seeds, better crop management practices, and more reliable agricultural recommendations.

Conclusion

Bioinformatics has become an important tool in modern agriculture. Although it works behind the scenes in research laboratories, its benefits are seen in the field through improved crop varieties, better disease management, and sustainable farming practices. By combining biology with computer technology, bioinformatics is helping agriculture become more productive, environmentally friendly, and resilient to climate change. Continued investment in bioinformatics research and stronger collaboration among scientists, agricultural institutions, and farmers will contribute to improved food security and better livelihoods for farming communities across India.



Beyond Brute Strength: The Emerging Science of Exoskeletal Support in Agriculture

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Introduction

Agricultural labour exacts a toll that rarely appears in yield reports or commodity prices: the slow, cumulative injury of the human musculoskeletal system. Work-related musculoskeletal disorders, the aches, strains and joint degeneration that follow years of repetitive bending, lifting and reaching, are now recognised as one of the most pervasive occupational health burdens in farming worldwide. A comprehensive scientific review of the field, screening more than 400 papers down to a working set of 70, found that harvesting tasks alone account for the majority of reported cases, with the lumbar spine, shoulders and wrists absorbing the greatest share of damage across crops as varied as rice, oil palm, orchard fruit and sugarcane. Where manufacturing and logistics have responded to comparable injury patterns with decades of ergonomic redesign and automation, agriculture, still overwhelmingly dependent on manual labour, has largely been left to absorb the cost. That gap helps explain why a technology with an unlikely lineage in military and industrial engineering has entered the field: the wearable exoskeleton.

How Passive Assistance Actually Works

An exoskeleton, in its simplest form, is a wearable frame that takes on some of the physical load your muscles would otherwise carry. Active exoskeletons use a motor, hydraulics or pneumatics to push or pull on your behalf actively. Passive exoskeletons do the same job without any of that machinery, storing energy in a spring, an elastic band or a gas strut as you bend or lift, then releasing it to assist you back up. In farm work, passive designs have a clear practical edge: no battery to charge, nothing to short out in a wet field, nothing that overheats



sitting in direct sun for a full shift. Most are also built around a single body region, the shoulder or the lower back, because the muscles under strain during rice planting are not the ones under strain during pole-harvesting. Weight matters too: most commercial passive units weigh well under 3 kilograms, light enough to wear through a full day without adding noticeably to fatigue.

By the Numbers

- 38-40% drop in shoulder muscle activity among real orchard workers wearing a passive exoskeleton
- Under 1 degree change in arm-lifting range while wearing the same device
- Up to 82% reduction in a targeted back muscle's workload in computer simulation, though placement mattered enormously
- 3 kg or less: typical weight of a commercial passive exoskeleton

Shoulder Support, Tested in Working Orchards

The strongest evidence on this technology did not come from a laboratory but from a working orchard. A team at Taiwan's National Sun Yat-sen University, led by Hsien-Min Wang, built a passive upper-limb exoskeleton around a gas spring and a four-bar linkage, and had orchard staff wear it while thinning fruit and spraying pesticide on pomelo and jujube trees. In laboratory testing beforehand, across two age groups spanning 25 to 64 years, the device had already shown a reduction in shoulder muscle activity of roughly 18 to 20 percent.





The PULE in use during a fruit-thinning task. Source: Wang, Le & Lin (2021), Applied Sciences, 11(2), 757 (CC BY 4.0).

In the orchard, the effect was considerably stronger. **Activity in the anterior deltoid, the shoulder muscle most burdened by repeated arm-raising, fell by close to 38 to 40 percent** during real spraying and thinning work, and participants rated the tasks as noticeably less exhausting. A motion-capture system found essentially no change in how far or how high workers could move their arms while wearing the device, under one degree of difference. The support, in other words, did not come at the cost of reach or control (Wang *et al.*, 2021).

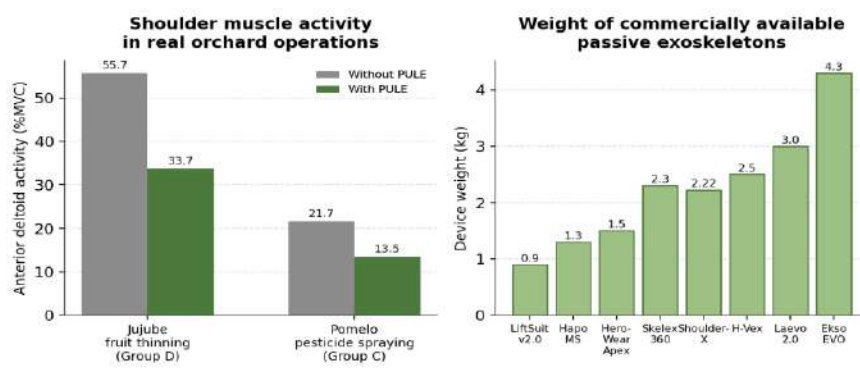


Figure 1. Shoulder-muscle activity with and without the exoskeleton during real orchard operations (left), and typical weight of comparable commercial devices (right). Source: Wang, Le & Lin (2021).

Back Support, and Its Trade-Off

Back-support exosuits address a different problem: tasks that require a bent trunk for long stretches, such as harvesting low-growing crops or cutting sugarcane. To test this, a team led by Sang Hyeon Kang, then at Iowa State University's Physical Ergonomics and Biomechanics Laboratory, evaluated a commercially available exosuit, the HeroWear Apex, on sixteen participants performing repeated three-minute harvesting drills while wearing electromyography sensors on their lower backs.

With the suit's elastic bands engaged, muscle fatigue in the lower back built up significantly more slowly than with the bands switched off, a genuine and measurable benefit. There was, however, a cost. Participants reported feeling more restricted in their movement with the suit active, and the deepest bend they could reach was measurably shallower, though their normal working posture was unaffected. The harness itself was not the issue; nobody reported discomfort from pressure or rubbing. The restriction was specifically about freedom of



movement. It is a useful reminder that a device can genuinely reduce muscle strain and still interfere with how naturally a person moves, a trade-off that only becomes visible once researchers ask workers how a device actually feels to use, not just what it measures (Kang *et al.*, 2025).

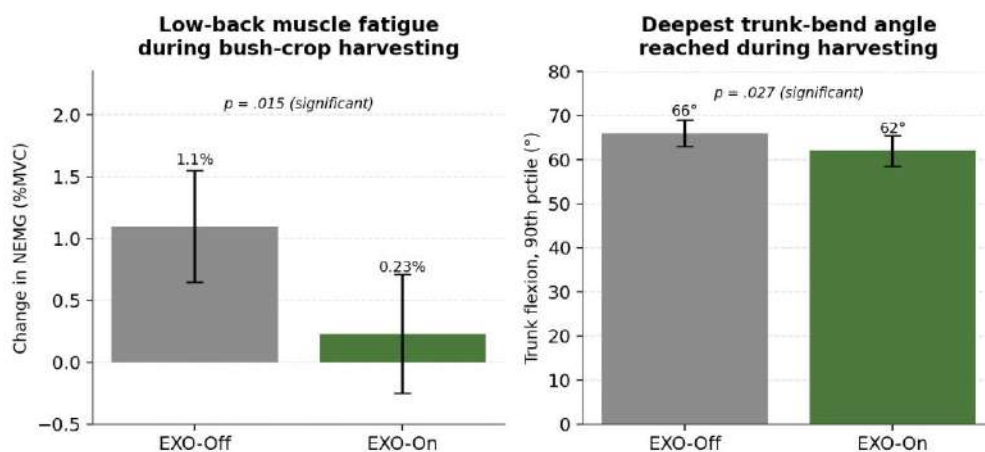


Figure 2. The exosuit reduced low-back fatigue but also reduced the deepest trunk-bending angle reached during simulated harvesting. Source: Kang, Wolf, Lowe & Mirka (2025).

What Computer Modelling Revealed Before Any Prototype Was Built

Physical prototypes are slow and expensive to test, so a team at Monash University Malaysia, led by Yon Sin Chan, took a different approach. They built a detailed computer model of the human back and simulated the strain of oil-palm harvesting, a task that involves repeatedly pulling down on a long-handled sickle to cut a fruit bunch free. Using motion data recorded from six experienced harvesters, the researchers tested what would happen if an elastic support element were attached to different muscles, one at a time.

Anchoring support to the rectus abdominis and the iliocostalis, two muscles at the front and side of the trunk, cut strain on the lower back by up to 45 percent. Supporting a different back muscle, the longissimus, reduced its own workload by more than 80 percent. Still, the simulation showed that load shifted onto the abdominal muscles instead, leaving the harvester no better off overall. The finding matters for anyone designing this kind of device: attaching support to "the back" is not automatically useful unless the specific muscle being targeted is the right one (Chan *et al.*, 2023).



Table 1: Comparative Overview of the Three Studies

Study (Institution)	Method	n	Device / Target	Principal Finding
Wang, Le & Lin (Nat. Sun Yat-sen Univ.)	Field trial + laboratory sEMG	18 (lab) + 8 (field)	PULE, shoulder	~38-40% reduction in field anterior deltoid activity; <1 deg change in range of motion
Kang, Wolf, Lowe & Mirka (Iowa State Univ.)	Controlled lab biomechanics, dynamic task	16	HeroWear Apex, lumbar	Delayed fatigue onset; reduced deep trunk flexion; increased perceived restriction
Chan, Teo, Gouwanda, Nurzaman & Gopalai (Monash Univ. Malaysia)	Musculoskeletal simulation (OpenSim)	6	Elastic exotendon, trunk	Up to 91% joint-moment reduction; muscle-specific placement critical to avoid load transfer

Adoption Is Not Only an Engineering Problem

A device that performs well in testing still has to be accepted by the people wearing it. The wider literature on this technology notes that most commercial passive exoskeletons come with detailed user manuals, and manufacturers are often willing to provide direct training, a meaningful detail, since a poorly fitted device can shift strain to an unintended part of the body rather than removing it. Surveys of workers who have tried these devices point to a more human obstacle as well: some are uneasy about the technology, concerned about misalignment or unexpected movement, and others quietly worry that being handed an "assistive" device signals that their role could eventually be automated. None of this argues against the technology. It does mean that introducing an exoskeleton on a farm needs to be treated as a change in how people work, with proper fitting and training, rather than simply a piece of equipment handed out on day one.



Where This Leaves the Industry

Taken together, these three studies point to a consistent pattern: passive, fabric-based, low-cost devices outperform rigid or motorised alternatives under real agricultural conditions, and small design choices, such as which muscle a strap is anchored to and how a harness distributes pressure, matter as much as the underlying spring technology. What stands out is that none of the devices reviewed here was designed specifically for farming; each is an adaptation of equipment built for construction sites or warehouses. There is also a geographic mismatch worth noting: the regions reporting the most agricultural musculoskeletal injuries are smallholder farms across South and Southeast Asia, while almost all exoskeleton research and manufacturing is concentrated in Europe, North America and East Asia. The biomechanics, on this evidence, are largely solved. Making a device affordable and relevant to the worker who actually needs it appears to be the harder problem, and the one the industry has yet to answer.

Conclusion

Passive exoskeletons offer a promising solution to reduce the physical burden of agricultural labour and address the growing issue of work-related musculoskeletal disorders among farmers. Studies show that lightweight, non-powered devices can reduce shoulder and lower-back muscle strain while allowing workers to maintain their natural range of movement. Successful adoption depends not only on biomechanical performance but also on affordability, comfort, proper training, and acceptance among farm workers. Future research should develop crop and task-specific exoskeletons designed for real agricultural environments, especially for smallholder farmers. With continued innovation, these technologies can improve worker health, productivity, and the long-term sustainability of farming operations.

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Biochar: Turning Waste into wealth for healthy soil and environment

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Global agriculture has made remarkable gains in food production over the past century, but this progress has come with a heavy environmental cost. Soil organic matter is being depleted, groundwater is being contaminated by overuse of synthetic fertilizers, and open burning of crop residues continues to release large quantities of carbon dioxide, methane and nitrous oxide into the atmosphere. Worldwide, agriculture generates billion of tones of crop residue every year, and a large share of it is either burnt in the field or left to decompose, instead of being converted into something useful. In countries where crop residue burning is a recurring seasonal problem, this represents both a wasted resource and a serious environmental hazard.

Biochar offers a practical solution to this problem. It is a porous, carbon-rich solid produced by heating biomass in a low-oxygen or oxygen-free environment, a process known as pyrolysis. The idea itself is not new. Indigenous communities in the Amazon basin created highly fertile, dark soils centuries ago by mixing charcoal, bones and organic waste into the ground, and these soils remain unusually fertile even today, thousands of years later. This historical example inspired modern scientific interest in deliberately producing biochar as a soil amendment, and it is now recognized internationally as a promising negative- emission technology that can help meet global climate goals while improving soil health and converting agricultural waste into a productive resource.

Advantages

- Biochar improves soil structure and increases water- holding capacity, helping crops cope better with dry spells and water-stressed conditions.
- It raises the cation exchange capacity of soils because of its alkaline nature, reducing aluminum and manganese toxicity that commonly limits crop growth in weathered tropical soils.



- Biochar neutralizes acidic soils because of its alkaline nature, reducing aluminum and manganese toxicity that commonly limits crop growth in weathered tropical soils.
- It stimulates beneficial soil microbial activity by providing habitat and a stable carbon source, improving nutrient cycling and enzymatic activity in the soil.
- Biochar locks carbon away in a highly stable form that can remain in soil for hundreds to thousands of years, making it a genuine long-term carbon sink.
- It reduces emissions of methane and nitrous oxide from agricultural soils, particularly in flooded paddy fields, adding climate benefits beyond carbon storage.
- Biochar can immobilize heavy metals such as lead, cadmium and chromium in contaminated soil and water, making it useful for remediation of polluted land.
- It converts an agricultural waste problem into an income-generating product, supporting rural livelihoods and reducing the need for open-field burning.

Major issues in promoting biochar

- ❖ High upfront cost of setting up consistent, quality-controlled biochar production units.
- ❖ Limited awareness among farmers about the benefits and correct application rates of biochar.
- ❖ Lack of mandatory quality standards, leading to wide variation in biochar quality between producers.
- ❖ Risk of contaminated feedstock introducing harmful substances such as polycyclic aromatic hydrocarbons into the final product.
- ❖ Limited long-term field validation, since most available studies cover only one to three growing seasons.
- ❖ Variable and sometimes uncertain crop response, depending heavily on soil type, climate and feedstock used.

Production methods of Biochar

Biochar can be produced through several thermochemical conversion processes, each suited to different feedstock and end uses.



Slow pyrolysis: Biomass is heated gently, generally between 300 and 500°C, over a long period. This method gives the highest biochar yield, along with a well-developed pore structure and good carbon stability, making it the most suitable route for agricultural application.

Fast pyrolysis: Biomass is heated very rapidly at higher temperature for only a few seconds. This route is optimized for producing liquid bio-oil rather than biochar, and the biochar obtained is of comparatively lower agronomic quality.

Gasification: Biomass undergoes partial combustion at high temperature, mainly to produce syngas. Biochar is only a minor by-product, with high surface area but lower carbon stability than slow-pyrolysis biochar.

Hydrothermal carbonization: This process treats wet biomass, such as sewage sludge or food waste, under hot, pressurized water without the need for pre-drying. The resulting hydro char shares many of the sportive and carbon-sorting properties of conventional biochar.

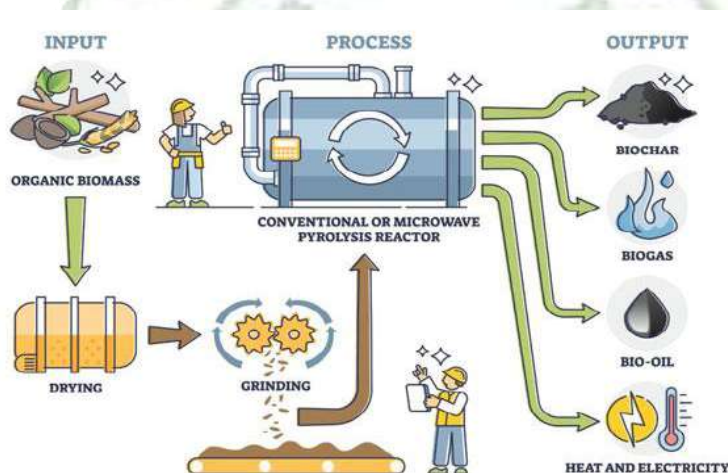


Fig. Production methods of Biochar

Feedstock material

The quality of biochar depends strongly on the type of feedstock used. Crop residues such as rice husk, wheat straw, corn cob and sugarcane bagasse are the most abundant and cost-effective sources for biochar production. Animal manures, such as poultry litter and dairy manure, yield nutrient-rich biochar with high phosphorus content and alkaline pH. Woody biomass, owing to its high lignin content, produces biochar with greater mechanical stability and longer carbon persistence in soil. Municipal and industrial waste, including sewage sludge and food-processing residues, allows useful recycling of urban waste streams, while algal biomass is an emerging feedstock particularly suited to coastal regions.



Quality and properties of Biochar

Pyrolysis temperature is the single most important factor governing biochar quality. As temperature increases up to around 700⁰C, porosity and surface area increase substantially, improving the material's capacity for water retention, nutrient adsorption and contaminant binding. Beyond this temperature, the pore structure begins to collapse. Carbon content rises sharply with temperature while oxygen and hydrogen content fall, and the material becomes progressively more alkaline, supporting its use as a natural liming agent for acidic soils. For soil application, well-prepared biochar should be reasonably uniform in particle size and low in moisture content to ensure consistent handling and field performance.

Issues in scaling up biochar adoption

- High cost of biochar relative to compost or inorganic fertilizer on a per-nutrient basis.
- Heavy capital investment required for industrial-scale, quality-controlled pyrolysis units.
- Absence of consistent national or regional quality standards for biochar producers.
- Weak agricultural extension supports to guide farmers on appropriate biochar selection and dosage.
- Logistical challenges in transporting bulky biochar from production sites to farms.
- Limited access to carbon credit markets for small and marginal farmers, despite the climate value of their practices.
- Cultural preference for familiar amendments such as compost and farmyard manure over a relatively unfamiliar technology.

Conclusions

Biochar offers a scientifically sound and practically achievable way to convert the burden of agricultural residue into a dual benefit of improved soil health and long-term carbon storage. The evidence reviewed here shows that, when produced from suitable feedstock under appropriate pyrolysis conditions and applied at the right rate, biochar consistently improves soil structure, fertility and water retention, increases crop yields, particularly in degraded and acidic soils, and reduces greenhouse gas emissions from agricultural land. At the same time,



its benefits are not universal: gains are smallest in soils that are already fertile or neutral, and the technology continues to face real barriers in cost, awareness and quality assurance.

For countries that generates large volumes of crop residue and continue to grapple with seasonal field burning, biochar presents an opportunity to address waste management, soil degradation and climate vulnerability at the same time. Realizing this potential will require coordinated effort on several fronts: establishing clear and enforceable quality standards, supporting long-term field trails across different agro-climatic zones, developing affordable production technology suited to small farms, and building stronger links between biochar producers, research institutions and policy makers. A with these foundations in place, biochar can become a genuine cornerstone of sustainable agriculture, turning waste into wealth and atmospheric carbon into stable soil carbon for the benefit of both farmers and the environment.





Biodegradable Packaging for Fresh Vegetable Storage

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Abstract

Fresh vegetables are highly perishable commodities that undergo rapid quality deterioration after harvest due to moisture loss, respiration, microbial spoilage, and physical damage. Conventional plastic packaging has been widely used to extend shelf life; however, concerns regarding environmental pollution and non-biodegradability have driven the search for sustainable alternatives. Biodegradable packaging materials derived from natural polymers such as starch, cellulose, chitosan, alginate, and polylactic acid (PLA) have emerged as promising solutions for fresh vegetable storage. These materials provide effective protection against moisture loss, oxidation, and microbial contamination while reducing environmental impact. Recent advancements in active packaging, edible coatings, nanocomposites, and intelligent packaging technologies have further enhanced the functionality of biodegradable packaging systems. This article discusses the principles, materials, innovations, benefits, challenges, and future prospects of biodegradable packaging for fresh vegetable storage.

Keywords: Biodegradable packaging, Fresh vegetables, Edible coatings, Sustainable storage, Active packaging

Introduction

Fresh vegetables are essential components of a healthy diet due to their rich content of vitamins, minerals, dietary fiber, and bioactive compounds. However, vegetables continue to respire after harvest, leading to moisture loss, senescence, and microbial deterioration. Packaging plays a crucial role in preserving quality and extending shelf life. Conventional petroleum-based plastics provide effective protection but contribute significantly to environmental pollution. Growing awareness of sustainability has accelerated the development of biodegradable packaging materials derived from renewable resources. These eco-friendly alternatives help



reduce plastic waste while maintaining vegetable freshness and safety. Consequently, biodegradable packaging has become an important area of research and commercial application in postharvest technology.

Need for Biodegradable Packaging in Vegetable Storage

The increasing use of synthetic plastic packaging has created serious environmental concerns due to its persistence in ecosystems. Plastic waste accumulation affects soil, water bodies, and wildlife. Consumers and policymakers are demanding sustainable packaging solutions that minimize environmental impact. Fresh vegetables require packaging that preserves quality while remaining environmentally friendly. Biodegradable materials decompose naturally through microbial activity, reducing waste accumulation. They provide a sustainable alternative without compromising product protection. Adoption of biodegradable packaging aligns with global goals for environmental conservation and circular economy development.

Principles of Biodegradable Packaging

Biodegradable packaging materials are designed to break down naturally into water, carbon dioxide, and biomass under appropriate environmental conditions. These materials are derived from renewable biological sources such as plants, microorganisms, and agricultural by-products. The packaging functions by creating a protective barrier around vegetables, reducing moisture loss and gas exchange. Some biodegradable materials possess antimicrobial and antioxidant properties that further enhance preservation. Proper packaging design helps maintain product quality during storage and transportation. The effectiveness of biodegradable packaging depends on material composition, environmental conditions, and the specific vegetable crop being stored.

Natural Polymers Used in Biodegradable Packaging

Several natural polymers are widely used for biodegradable packaging production. Starch-based materials are inexpensive, renewable, and readily biodegradable. Cellulose and its derivatives provide excellent mechanical strength and transparency. Chitosan, obtained from crustacean shells, possesses antimicrobial properties that help reduce microbial spoilage. Alginate derived from seaweed forms effective edible films and coatings. Protein-based materials such as gelatin and soy protein are also used in biodegradable packaging formulations. These natural polymers offer sustainable alternatives to conventional plastics and support environmentally friendly postharvest management systems.



Edible Coatings and Films for Vegetable Preservation

Edible coatings represent an important category of biodegradable packaging technologies. These thin layers are applied directly to vegetable surfaces and act as semipermeable barriers. Edible coatings reduce moisture loss, delay respiration, and inhibit microbial growth. Common coating materials include chitosan, alginate, pectin, starch, and cellulose derivatives. The incorporation of natural antioxidants and antimicrobial agents further enhances preservation efficacy. Edible coatings maintain freshness, improve appearance, and extend shelf life. Their biodegradability and safety make them attractive for commercial vegetable storage applications.

Active Packaging Technologies

Active packaging systems interact with the packaged product to improve preservation. These systems incorporate antimicrobial, antioxidant, moisture-absorbing, or ethylene-scavenging components. Natural plant extracts, essential oils, and bioactive compounds are frequently used as active agents. Active packaging helps suppress microbial growth and delays physiological deterioration. Ethylene scavengers are particularly beneficial for slowing ripening processes in certain vegetables. This technology enhances shelf life while reducing reliance on chemical preservatives. Active biodegradable packaging combines sustainability with advanced preservation functionality.

Nanotechnology in Biodegradable Packaging

Nanotechnology has significantly improved the performance of biodegradable packaging materials. Nanoparticles enhance mechanical strength, barrier properties, and antimicrobial activity. Silver nanoparticles, zinc oxide nanoparticles, and nanocellulose are commonly incorporated into biodegradable films. These materials improve resistance to oxygen and moisture transmission. Nanotechnology also enables controlled release of antimicrobial compounds. Smart nanocomposite packaging systems provide better protection against spoilage organisms and environmental stresses. Such innovations are expanding the commercial potential of biodegradable packaging for fresh vegetables.

Intelligent Packaging for Fresh Vegetable Storage

Intelligent packaging systems provide information about product quality and storage conditions. Sensors embedded within packaging materials can monitor temperature, humidity, gas composition, and microbial activity. Color-changing indicators help consumers assess



product freshness. Radio Frequency Identification (RFID) technology enables traceability throughout the supply chain. Intelligent packaging improves quality control and reduces food waste. When combined with biodegradable materials, these systems offer environmentally sustainable and technologically advanced solutions for vegetable storage and distribution.

Benefits of Biodegradable Packaging

Biodegradable packaging offers numerous advantages for fresh vegetable preservation. It reduces environmental pollution and dependence on petroleum-based plastics. Improved moisture retention and gas regulation help maintain vegetable quality. Many biodegradable materials possess natural antimicrobial properties that reduce spoilage. These packaging systems contribute to food safety and shelf-life extension. They support sustainable agricultural and food supply chains. Increasing consumer preference for eco-friendly products is further driving market adoption. Overall, biodegradable packaging promotes both environmental and economic sustainability.

Challenges and Limitations

Despite its advantages, biodegradable packaging faces several challenges. Production costs are often higher than conventional plastics. Some materials have lower mechanical strength and moisture resistance. Large-scale manufacturing and commercialization remain limited in certain regions. Packaging performance may vary depending on storage conditions and vegetable type. Regulatory approval and standardization of biodegradable materials also present challenges. Research is ongoing to improve material properties and reduce costs. Addressing these limitations will enhance broader adoption of biodegradable packaging technologies.

Future Prospects

The future of biodegradable packaging is highly promising due to increasing environmental awareness and technological advancements. Development of multifunctional materials with enhanced barrier and antimicrobial properties will improve packaging performance. Nanotechnology and biotechnology will facilitate the creation of more efficient biodegradable systems. Smart packaging integrated with sensors and digital technologies will revolutionize fresh produce storage. Utilization of agricultural waste materials for packaging production will support circular bioeconomy initiatives. Continued innovation and commercialization will expand the role of biodegradable packaging in sustainable food systems.



Conclusion

Biodegradable packaging represents a sustainable and innovative solution for fresh vegetable storage. Materials derived from renewable resources such as starch, cellulose, chitosan, and alginate provide effective protection while reducing environmental impact. Advances in edible coatings, active packaging, nanotechnology, and intelligent packaging systems have significantly enhanced preservation efficiency. Although challenges related to cost and performance remain, ongoing research and technological development continue to improve these materials. The adoption of biodegradable packaging will play a vital role in reducing plastic pollution, extending vegetable shelf life, and supporting sustainable postharvest management practices.

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Cluster bean: a low water requirement crop of arid regions

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Cluster bean *Cymopsis tetragonoloba* (L.) Taub commonly known as guar is a cash crop of the family *Leguminosae*. It is a self-pollinated crop with $2n = 14$ chromosomes and a hardy drought tolerant annual legume. It is one of the most important vegetable cum industrial crops grown for its tender vegetable pod and seed endospermic gum (30-35%). Cluster bean is a rich source of protein, fibres, vitamin A and C. Guar seed is highly valued in numerous industries because of its galactomannan rich endosperm. Its nutritional and industrial value relies on one of the significant hydrocolloid products with high-thickening strength which constitutes 78-82% of the endosperm. Guar gum is used in mining, petroleum drilling and textile manufacturing sectors. The gum is refined to make a yellowish white powder which is an important raw material in many industries. Cluster bean is also used as cattle feed and green manure crop which enrich the soil by fixing atmospheric nitrogen (50-60 kg/ha) and by addition of organic matter.

The world's total production of guar figures around 7.5 to 10 lakh tonnes of guar every year, 80% of world production occurs in India, In India cluster bean occupies an area of 3343.7 thousand hectares with a production of 1169.3 thousand tones, and productivity of 350kg/ha. Most of the area is concentrated in North-Western parts of the states, viz, Rajasthan, Haryana, Gujarat and Punjab Uttar Pradesh, Madhya Pradesh, Tamil Nadu, Maharashtra, Karnataka and Andhra Pradesh. The net worth of the Indian exports is estimated over Rs 500 cores.

It is an important arid legume crop whose cultivation is mainly concentrated in marginal and sub-marginal soils receiving low rainfall (300-400 mm). Because of its wide variety of uses and suitability to drought conditions it could be an alternative crop for arid and semi-arid tracts of India. Cluster bean is a warm-season crop highly adaptable to regions with low rainfall and high temperature and grows well in summer and rainy seasons in the plains. Water requirement for cluster bean is very minimum and being a short duration crop, it can be grown during summer. It also has soil fixing characteristics that makes it fit well into a crop rotation cycle.

For crop diversification and sustainable agriculture, area and production of arid legumes in dry land regions could be enhanced by horizontal expansion of these crops in low rainfall areas.



Considering its use as vegetable, industrial utility and adaptability to arid and drought conditions, this crop has got great potential for its improvement and development of varieties suitable to specific agro ecological conditions.

In spite of great significance of this crop in regional, national and climatologically context, its poor productivity is still a continued concern. Hence, research results of great practical and scholarly significance are required for its genetic improvement. Varieties with high yield, disease resistance, and more seeded pods are few. In order to enhance the production of this crop to the greater extent there is an urgent need of evolving new variety with combination of all beneficial factors.

An attempt was made to screen cluster bean germplasm at ICAR- CRIDA to understand the adaptability of this crop to Semi-Arid dryland tracts of peninsular India and found that the crop is invariably affected by powdery mildew due to the congenial environment present in this region. So we made this challenging situation to screen the germplasm for powdery mildew resistance and identified few germplasms are tolerant to this disease in this hot spot for this disease.





Climate-Smart Food Systems: Integrating Green Innovations and Emerging Technologies for Sustainable Development

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Abstract

Climate change, environmental degradation, resource depletion, and rapid population growth pose significant challenges to global food security and agricultural sustainability. Climate-Smart Food Systems (CSFS) have emerged as a holistic framework that integrates sustainable agricultural practices, renewable energy solutions, and advanced digital technologies to enhance productivity, strengthen resilience to climate change, and minimize environmental impacts across the food value chain. Green innovations such as precision agriculture, conservation agriculture, protected cultivation, and circular bioeconomy approaches improve resource-use efficiency, soil health, and environmental sustainability. Renewable energy technologies, including solar energy, bioenergy, and agrivoltaics, contribute to reducing greenhouse gas emissions while supporting sustainable food production and energy security. Emerging technologies such as artificial intelligence (AI), the Internet of Things (IoT), remote sensing, drones, and blockchain are transforming agricultural systems through data-driven decision-making, optimized resource management, and improved supply chain transparency. Climate-smart horticulture further enhances food and nutritional security under changing climatic conditions. The integration of green innovations and advanced technologies offers a promising pathway toward resilient, resource-efficient, and environmentally sustainable food systems capable of meeting the needs of present and future generations.

Keywords: Climate-smart food systems; Sustainable; Green innovations; Renewable energy; Food security; Technologies.



Introduction

Climate change, population growth, depletion of natural resources and environmental degradation are unique challenges for the global food system. Agriculture feeds, clothes and provides livelihoods for billions, but is highly vulnerable to climate change. Climate change (e.g., increasing temperatures, changes in rainfall, droughts, floods and other extreme weather events) endangers the global agricultural productivity and food security (IPCC, 2022). The global population is projected to grow to nearly 10 billion by 2050, intensifying the pressure to produce more food while conserving natural resources. Conventional food production systems are often associated with greenhouse gas emissions and environmental degradation, caused by their heavy dependence on fossil fuel inputs, intensive irrigation and overuse of chemical inputs (FAO, 2021).

To address these challenges and to transform the way food is produced, processed, distributed and consumed, the Climate-Smart Food Systems (CSFS) integrated approach has been developed. Climate-smart food systems use sustainable agricultural practices, renewable energy technologies and digital innovations to increase productivity, improve resilience to climate change and reduce environmental impacts (FAO, 2013). The integration of green innovation and emerging technologies to climate smart food systems presents good prospects for sustainable development and long-term food security.

Understanding Climate-Smart Food Systems

Climate smart food systems are a climate smart agriculture beyond the farm gate, covering the entire food value chain. It includes all the activities and action involved in the production, processing, transport, marketing, consumption and disposal of food products.

The three main goals of climate-smart food systems are to:

1. Agricultural long-term productivity and income gains.
2. Building resilience and adaptive capacity to climate change
3. Reduce environmental degradation and greenhouse gas emissions (FAO, 2013).

It is about the nexus of agriculture, energy, water, biodiversity and human nutrition. Climate-smart food systems aren't about more production. These systems contribute to efficiency, resilience and sustainability of the entire food production and consumption chain.



Climate Change and Vulnerability of Food Systems

Climate change affects all parts of the food system. The productivity of crops is increasingly constrained by heat stress, water scarcity, changes in precipitation patterns and new pests and diseases. Reduced feed availability, heat stress and increase of incidence of disease affect livestock production (IPCC, 2022).

Horticultural crops (fruits and vegetables) are especially vulnerable to climate variability. High temperature can negatively affect traits related to flowering, pollination, fruit set and fruit quality. Water stress may cause large yield loss and/or higher production cost. Changes in temperature and humidity are likely to change the dynamics of pests and diseases, making it more difficult for growers.

Climate change impacts food supply-chain. Extreme weather events can impede market access, damage transport infrastructure and increase post-harvest losses (Godde et al., 2021). Now we need to build climate change resilience into the food value chain.

Green Innovations: Transforming Food Systems

Precision Agriculture

Precision agriculture is one of the most important innovations for climate-smart food systems. Technologies such as GPS, sensors, drones, remote sensing and geographic information systems are used for optimizing agricultural inputs and management practices (Wolfert et al., 2017).

With precision agriculture farmers can manage water, fertilisers and pesticides on site according to the needs of the crop. This means better resource use, lower production costs and a reduced environmental impact.

Conservation Agriculture

Conservation agriculture is a farming system based on three principles: minimum tillage, permanent soil cover and crop rotation. These practices improve soil health, reduce erosion and increase water retention and carbon sequestration (Lal, 2020). Healthy soils build climate resilience through better nutrient cycling, drought tolerance and long-term productivity.



Protected Cultivation

Technologies of protected cultivation such as green houses, poly houses, net houses and low tunnels offer controlled environment to the crops and safeguard from adverse weather conditions. These systems assist in the production of all seasons, enhance water use efficiency, and improve crop quality (Shamshiri et al., 2018). Special advantage of protected cultivation of horticulture crops is that it helps the farmers to overcome the adverse effect of variation of temperature, heavy rain falls and pest attack.

Circular Bioeconomy

The circular bioeconomy seeks to minimize waste and increase resource efficiency. Food waste, agricultural residues and other organic by-products into compost, biofertilizers, bioenergy and other value-added products (Benke and Tomkins, 2017). Such practices reduce pollution to the environment and create more economic opportunities for farmers and rural society.

Renewable Energy in Climate-Smart Food Systems

Renewable energy is increasingly considered an important component of sustainable food systems. Energy is required at every stage of the entire food value chain, whether it is for irrigation, mechanisation, processing, transportation, storage or refrigeration. Transitioning from fossil fuels to renewable energy sources can drastically reduce greenhouse gas emissions and improve energy security.

Solar Energy

Solar energy is one of the most widely used renewable energy technologies in agriculture today. Solar irrigation systems substitute diesel and offer a reliable water supply. Solar dryers are used to reduce the moisture content of fruits, vegetables and spices and helps in preservation and increasing shelf life (Matheri et al., 2024).

Of special note is the importance of solar powered cold storage facilities in reducing post-harvest losses of horticultural crops. These facilities will improve the quality of the products and the market opportunities when they are well stored.

Bioenergy

Agricultural residues, animal manure and food processing waste can be used to produce bioenergy through gasification and biomass combustion technologies. Production of bioenergy



provides renewable energy and contributes to waste management and reduction of emission of green gases (Matheri et al., 2024).

Agrivoltaics

Agrivoltaics is the simultaneous production of solar photovoltaic (PV) electricity and crops on the same land. This new approach improves land use efficiency by growing food and energy at the same time (Barron-Gafford et al., 2019). Partial shading of solar panels may result in a decrease in evapotranspiration, better protection of soil moisture and protection of crops from extreme heat. Agrivoltaics systems therefore offer promising perspectives for climate change adaptation through the generation of additional income from renewable energy production.

Emerging Technologies Driving Climate-Smart Food Systems

Artificial intelligence (AI)

Artificial intelligence is revolutionizing the agriculture sector by facilitating data driven decision making. AI systems can analyse large data sets to predict crop yields, detect diseases, optimize irrigation schedules and enable precise nutrient management (Javaid et al., 2022). They allow farmers to do more with less, fewer resources and less harm to the environment.

Internet of Things (IoT)

The Internet of Things (IoT) is a network of connected devices and sensors that can communicate in real time. Soil moisture sensors, weather stations and crop monitoring systems provide the data needed to practice precision agriculture and to adapt to climate change. IoT technologies enable the farmers to adapt fast to the dynamic changes of the environment and to improve the efficiency of resources (Shamshiri et al., 2018).

Remote Sensing and Drones

Drones equipped with high resolution cameras and sensors are increasingly used for monitoring crops, nutrients, pest detection and yield estimation. Remote sensing technologies can be useful to obtain information about crop health, soil conditions and water availability (Klerkx et al., 2020). These technologies can be used for informed decision making and enhance the efficiency of the agricultural operations.



Blockchain Technology

Blockchain technology can contribute to transparency and traceability in the food supply chain. Consumers will know how the product is made, where it comes from and the quality assurance. This will boost trust and food safety (Yli-Huumo et al., 2016).

Climate-Smart Horticulture and Food Security

Horticulture's role in food and nutrition security It grows vegetables, spices and medicinal plants. Horticulture, on the other hand, is very sensitive to climate variability. Climate smart horticulture is the combination of sustainable technologies and management practices to improve productivity, resilience and environmental sustainability. Some of the key interventions include climate resilient varieties, precision irrigation, protected cultivation, mulching, integrated nutrient management and renewable energy driven systems (Klerkx et al., 2020).

Protected cultivation, sensor-based irrigation, solar powered water pumping and renewable energy based cold storage facilities are the potential tools to increase productivity and reduce post-harvest losses. These technologies are highly relevant for sustainable food systems and for better nutrition outcomes.

Challenges and Future Directions

Climate smart food systems have enormous potential but also face a number of challenges. However, high initial investment cost, lack of technical knowhow, poor infrastructure and limited access to finance often hinder adoption, especially by the small-scale farmers.

Rural communities often lack the internet connections and technical support that digital technologies require. Also, these need to be adapted to the local environment and socio-economic conditions to be effective.

Future work should boost research and innovation, train farmers, improve access to renewable energy technologies and create enabling policy frameworks. Public-private partnerships and international cooperation will be equally important to speed up the transition to sustainable food systems.

Conclusions

Climate-smart food systems offer a holistic solution to the twin issues of food security, climate change and environmental sustainability. Green innovations, renewable energy technologies



and emerging digital tools can make these systems more productive, more resilient and have less environmental impacts. Sustainable alternatives to fossil fuels can be provided by renewable energy sources such as solar energy, bioenergy and agrivoltaics. AI, IoT, drones and remote sensing improve decision making and resource efficiency. Climate-smart horticulture is also a pathway for innovations for sustainable production of nutritious food. As climate change risks increase, climate-smart food systems will be needed to feed future generations and to deliver sustainable development goals.

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Invaders Beneath the Waves: The Economic Toll of Invasive Fish Species in India

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Introduction

India's freshwater and marine ecosystems are home to an astonishing diversity of more than 2,953 fish species (NBFGR, 2025), many found nowhere else in the world. But beneath the surface, an ecological battle is taking place. Invasive fish species introduced intentionally or accidentally are spreading fast and threatening native biodiversity fishers livelihoods and the nation's economy (Haubrock *et al*, 2022). The exotic fishes introduced into India for different purposes covers nearly 13.6% of total fish diversity (Joshi *et al*, 2021). Due to wider tolerance limit some alien fish species have acclimatised to diverse eco-climatic conditions.

When Strangers Take Over

Invasive species are non-native organisms that establish spread and cause harm to the environment, economy or human health (Xie J, 2023). In Indian waters, several such species have found a comfortable home. The most notorious include the African catfish (*Clarias gariepinus* or *Thai magur*), common carp (*Cyprinus carpio*), tilapia (*Oreochromis mossambicus*), and more recently, the red-bellied piranha (*Pygocentrus nattereri*) and suckermouth catfish (*Hypostomus plecostomus*) (Bipul Phukan and Niti Sharma, 2020 and Mahapatra and Mohanty, 2023)

While some of these species were brought in with good intentions for aquaculture, weed control and ornamental purposes they have often escaped confinement and multiplied in natural waters, displacing local species.



The Economic Bite

The economic loss from invasive fish species in India is significant though difficult to fully estimate. According to studies by the National Bureau of Fish Genetic Resources (NBFGR), exotic species now constitute over 35% of India's total aquaculture production, but their invasion into natural systems has caused local fish populations to collapse especially in rivers and reservoirs.

In states such as Tamil Nadu, Kerala and West Bengal, fishers have reported declines in catches of native species such as *Labeo rohita* and *Catla catla*, largely due to competition from invasive species such as tilapia and common carp. These ecological changes have led to reduced catch volumes and economic instability in several inland fisheries (FAO, 2020; CIFRI, 2022).

Invasive predators like the African catfish, which grow fast and eat almost anything, have devastated small-scale fishers' nets and stocks. Meanwhile, the armored suckermouth catfish, often discarded from aquariums, clogs nets and damages riverbeds making fishing labor-intensive and less profitable (Chander, 2016, Singh et al. 2015, and Roy et al. 2022).

A 2022 report by the ICAR-NBFGR estimated that India may be losing hundreds of crores annually in direct and indirect losses due to invasive aquatic species, considering their impact on fish catch, biodiversity, and water ecosystem management costs.

Biodiversity Loss/Economic Loss

The problem isn't just about numbers — it's about ecological balance. Native species like *Tor putitora* (mahseer) and *Mystus cavasius* (tengra) are culturally and economically important but are being pushed out of their habitats. As these native stocks decline, fishers must travel farther, spend more on fuel, and get smaller returns, creating a ripple effect of economic stress.

Tourism and aquaculture sectors also feel the heat. Lakes infested with tilapia or suckermouth catfish lose their scenic value and fish diversity, hurting eco-tourism and recreational angling industries (Tayade, 2023)

How They Sneak In

The pathways are varied like aquaculture escapees, ballast water from ships, ornamental fish trade, or even deliberate release by unaware fish farmers. For instance, tilapia was once promoted for fast growth but its uncontrolled spread into reservoirs now threatens native biodiversity.



Fighting Back the Invaders

India has begun taking action. The ICAR-NBFGR maintains a National Surveillance Programme for Aquatic Animal Diseases and monitors invasive species (MFAH&D, 2025). The farming and breeding of the exotic African catfish is banned in all states and Union Territories across India due to the species' predatory nature and the severe threat it poses to native aquatic biodiversity and ecosystems.

Awareness campaigns, strict regulation of exotic species import, and habitat restoration are steps in the right direction. However, policy enforcement and fisher-level awareness remain weak. Many small-scale fish farmers are unaware of the ecological dangers and continue to stock invasive species for short-term gains.

Conclusion

Managing invasive fish species is not just an environmental issue, it's an economic and livelihood challenge. Protecting native fish populations means protecting the income and food security of millions of fishers across India. India needs stronger biosecurity laws, better screening of exotic species, and promotion of native species in aquaculture. Scientific management combined with local awareness can turn the tide. As India strives toward sustainable fisheries and blue economy goals, keeping invaders in check is essential. After all, the health of our waters determines the health of our communities.

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Enhancing Strawberry Quality and Shelf Life through Gibberellic Acid (GA₃) Treatment

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Introduction

Strawberry (*Fragaria × ananassa* Duch.) is one of the most attractive and commercially important fruit crops grown throughout the world. Its bright red colour, pleasant aroma, delicate texture, and unique flavour make it highly popular among consumers of all age groups. Apart from its appealing taste, strawberry is also recognized as a rich source of vitamins, minerals, dietary fibre, and antioxidant compounds such as anthocyanins, flavonoids, and phenolic acids. These bioactive compounds contribute significantly to human health by reducing the risk of cardiovascular diseases, certain cancers, and age-related disorders.

Despite its immense popularity and nutritional value, strawberry cultivation faces a major challenge due to the highly perishable nature of the fruit. Strawberries have a soft texture, high moisture content, and rapid respiration rate, which make them susceptible to mechanical injury, moisture loss, microbial infection, and physiological deterioration immediately after harvest. Under normal conditions, strawberry fruits can retain acceptable quality for only a few days, resulting in significant post-harvest losses during transportation, storage, and marketing. Therefore, improving fruit quality and extending shelf life have become important objectives for strawberry growers, researchers, and the fruit processing industry.

Among the various approaches employed to enhance post-harvest performance, the application of plant growth regulators has gained considerable attention. One such growth regulator is gibberellic acid (GA₃), which plays a vital role in regulating plant growth and fruit development. Recent research has demonstrated that post-harvest dipping of strawberry fruits in GA₃ solutions can positively influence fruit quality and storage behaviour, thereby offering a practical and economical solution for reducing post-harvest losses.



Understanding Gibberellic Acid

Gibberellic acid is a naturally occurring plant hormone belonging to the gibberellin group. It was first discovered in association with the fungus *Gibberella fujikuroi*, which caused abnormal elongation in rice plants. Since its discovery, GA₃ has been extensively studied and widely used in horticultural crops due to its ability to regulate various physiological processes.

In plants, gibberellic acid promotes cell division, cell elongation, seed germination, flowering, fruit set, and fruit growth. It influences metabolic activities by stimulating enzyme production, enhancing nutrient mobilization, and regulating the synthesis of structural compounds within plant tissues. These physiological effects contribute to improved growth and development of fruits and vegetables.

In fruit crops, GA₃ has been reported to improve fruit size, shape, colour development, and overall marketability. Additionally, its influence on cellular integrity and metabolic processes can delay senescence, thereby contributing to extended storage life and better post-harvest quality.

Strawberry Quality and Post-Harvest Challenges

The quality of strawberry fruits is determined by several physical, chemical, and sensory attributes. Consumers generally prefer fruits that possess an attractive appearance, bright colour, firm texture, pleasant aroma, balanced sweetness and acidity, and high nutritional value. Maintaining these quality parameters after harvest is often difficult because strawberries continue to undergo physiological and biochemical changes during storage. Following harvest, strawberry fruits experience rapid respiration and transpiration. These processes result in moisture loss, softening of tissues, degradation of pigments, decline in sugar content, and increased susceptibility to microbial attack. Consequently, fruits lose their freshness, visual appeal, and nutritional quality within a short period.

The challenge becomes even more significant in regions where cold storage facilities are limited or where fruits must travel long distances before reaching consumers. Under such circumstances, strategies that can slow down deterioration and preserve fruit quality become essential for minimizing economic losses.

Role of GA₃ in Improving Fruit Quality

The beneficial effects of gibberellic acid on fruit quality can be attributed to its influence on several physiological and biochemical processes. When strawberry fruits are dipped in GA₃



solution, the hormone penetrates the fruit tissues and affects cellular metabolism in a manner that promotes quality retention.

One of the primary effects of GA₃ is the enhancement of cell expansion and maintenance of cell turgidity. This contributes to better fruit size and firmness, two important characteristics that determine consumer acceptance and market value. Firm fruits are less prone to mechanical damage during handling, packaging, and transportation. GA₃ also influences the accumulation and preservation of sugars, organic acids, and other biochemical constituents responsible for fruit flavour and taste. By regulating metabolic activities, the hormone helps maintain a desirable balance between sweetness and acidity, thereby preserving sensory quality during storage.

Another important aspect is the preservation of fruit colour. The attractive red colour of strawberries is mainly due to anthocyanin pigments. During storage, degradation of these pigments may occur, leading to a decline in visual appeal. Gibberellic acid helps maintain cellular stability and delays pigment degradation, allowing fruits to retain their attractive appearance for a longer duration. Furthermore, GA₃ has been associated with enhanced antioxidant activity in fruits. Antioxidants play a crucial role in protecting plant tissues from oxidative damage caused by reactive oxygen species generated during respiration and senescence. By reducing oxidative stress, GA₃ contributes to prolonged freshness and improved nutritional quality.

Influence of GA₃ on Shelf-Life Extension

Shelf life refers to the period during which a fruit remains safe, nutritious, and acceptable for consumption. In strawberries, shelf life is typically limited due to rapid softening and microbial spoilage. The application of gibberellic acid has emerged as an effective method for delaying these deterioration processes.

One of the key mechanisms through which GA₃ extends shelf life is the reduction of physiological ageing or senescence. The hormone slows down metabolic activities associated with tissue breakdown, thereby delaying the onset of fruit softening. This allows strawberries to maintain their structural integrity for a longer period after harvest. GA₃ also contributes to reduced moisture loss during storage. Since water loss is a major factor responsible for shrivelling and weight reduction in fruits, maintaining moisture content is essential for preserving freshness and appearance. Fruits treated with GA₃ generally exhibit lower weight loss compared to untreated fruits.



Another significant benefit involves the maintenance of membrane integrity. Cellular membranes act as barriers that regulate the movement of substances within plant tissues. As fruits age, membrane deterioration accelerates leakage of cellular contents and promotes microbial growth. Gibberellic acid helps stabilize these membranes, reducing tissue breakdown and extending storage life. By delaying senescence, reducing moisture loss, and maintaining cellular integrity, GA₃-treated fruits remain marketable for longer periods, offering substantial benefits to growers, traders, and consumers.

Research Findings on Strawberry cv. Chandler

A field experiment conducted during 2022-23 at the Research Farm of the Department of Agriculture, Sant Baba Bhag Singh University, Jalandhar, Punjab, evaluated the influence of different concentrations of gibberellic acid on the quality and shelf life of strawberry cv. Chandler under open-field conditions.



Figure 1 Preparation of raised beds



Figure 2 Bed



Figure 3 Application of plastic mulch



Figure 4 Irrigation and Establishment of strawberry plants



Figure 5 Flowering stage of strawberry cv. Chandler

The cultivar Chandler is widely cultivated because of its high yield potential, attractive fruit appearance, excellent flavour, and consumer preference. However, like many strawberry cultivars, Chandler is highly perishable and requires effective post-harvest management to maintain quality. In this study, harvested fruits were subjected to dipping treatments using different concentrations of gibberellic acid. Various quality parameters and storage characteristics were subsequently evaluated during the storage period.



Figure 6 Fruit development stage



Figure 7 Mature fruit stage

The results clearly demonstrated that GA₃ treatments significantly influenced fruit quality and shelf life. Among all the concentrations tested, the treatment involving a 70 ppm GA₃ dip produced the most favourable outcomes. Fruits treated with 70 ppm GA₃ exhibited superior growth characteristics, improved quality attributes, and enhanced storage behaviour compared to other treatments. The observed improvements may be attributed to the optimal physiological response achieved at this concentration. Lower concentrations may not provide sufficient hormonal stimulus, while excessively high concentrations could potentially disrupt normal metabolic balance. The 70-ppm treatment appears to provide the ideal level of hormonal regulation required for maximizing fruit quality and storage performance.



Figure 8 Post-harvest GA₃ dipping treatment



Figure 9 Harvested fruits of strawberry cv. Chandler

Consequently, the study identified 70 ppm GA₃ as the most effective concentration for improving fruit quality and extending the shelf life of strawberry cv. Chandler under open-field cultivation conditions.

Practical Implications for Strawberry Growers

The findings of this research hold significant practical importance for strawberry producers. Post-harvest losses represent a major economic burden in strawberry cultivation, often reducing profitability despite high production costs. The adoption of a simple GA₃ dipping treatment can help mitigate these losses by improving fruit quality and prolonging marketability.

Improved shelf life enables growers to transport fruits over longer distances without substantial deterioration. This expands marketing opportunities and allows producers to access distant



markets where better prices may be available. Enhanced fruit quality also increases consumer satisfaction and market demand, contributing to higher economic returns. From a commercial perspective, GA₃ dipping is relatively simple, cost-effective, and easy to incorporate into existing post-harvest handling practices. Since the treatment does not require sophisticated infrastructure, it can be adopted by both small-scale and large-scale growers.

Conclusion

Strawberry is a highly valued fruit crop whose commercial success is often constrained by its short shelf life and rapid post-harvest deterioration. Gibberellic acid has emerged as an effective tool for enhancing fruit quality and extending storage life through its influence on physiological and biochemical processes. By improving fruit firmness, maintaining colour and flavour, reducing moisture loss, and delaying senescence, GA₃ helps preserve the overall quality of strawberry fruits during storage.

Research conducted on strawberry cv. Chandler under open-field conditions demonstrated that post-harvest dipping of fruits in 70 ppm gibberellic acid produced the best results in terms of fruit quality and shelf-life extension. The findings highlight the potential of GA₃ as a practical and economically viable post-harvest treatment for reducing losses and improving profitability in strawberry cultivation.

As consumer demand for high-quality fresh fruits continues to grow, the adoption of scientifically validated technologies such as GA₃ dipping can play an important role in enhancing the sustainability and competitiveness of strawberry production systems.



Strengthening Fisheries Through Effective Extension and Stakeholder Participation

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Abstract

Fisheries and aquaculture play a vital role in food security, employment generation, nutritional well-being, and economic development. However, the sector faces growing challenges, including climate variability, resource degradation, disease outbreaks, market uncertainties, and limited access to modern technologies. Effective fisheries extension has therefore become essential for transferring knowledge, technologies, and innovations while strengthening the capacity and resilience of fishing and aquaculture communities. Modern extension has evolved from conventional technology dissemination towards participatory, stakeholder-oriented, and innovation-driven approaches. Fishers and fish farmers are increasingly recognized as active partners in identifying problems, testing technologies, and developing locally appropriate solutions. Extension personnel, research institutions, government agencies, universities, non-governmental organizations, cooperatives, and private-sector organizations collectively contribute to capacity building, technology adoption, market linkages, and sustainable resource management. Participatory approaches such as Farmers' Field Schools, Farming Systems Research and Extension, and community-based extension promote experiential learning, empowerment, and locally relevant decision-making. The emerging Fisheries Innovation System further emphasizes continuous interaction and knowledge exchange among diverse stakeholders, recognizing technological, institutional, organizational, and social innovation as interconnected components of sustainable development. Strengthening stakeholder participation, institutional coordination, communication networks, and collaborative learning can improve productivity, livelihoods, market access, climate resilience, and the long-term sustainability of fisheries and aquaculture.



Introduction

Fisheries and aquaculture contribute significantly to food security, nutritional well-being, employment generation, and economic development worldwide. However, the sector faces numerous challenges, including climate variability, resource degradation, disease outbreaks, market uncertainties, and limited access to modern technologies. Fisheries extension plays a crucial role in addressing these challenges by facilitating the transfer of knowledge, technologies, and innovations from research institutions to fishing communities. Modern fisheries extension has evolved beyond the traditional concept of technology dissemination and now emphasizes participatory learning, stakeholder engagement, and innovation-driven development. Effective fisheries extension helps improve productivity, strengthen livelihoods, promote sustainable resource management, and enhance the resilience of fisheries-dependent communities (FAO, 2022).

Stakeholders in Fisheries Extension

Fisheries extension operates through the active participation of multiple stakeholders who contribute to the generation, dissemination, and utilization of knowledge and technologies. Among these stakeholders, fishers and fish farmers represent the primary beneficiaries as well as the key drivers of innovation adoption. Their practical experience, indigenous knowledge, and direct interaction with aquatic ecosystems provide valuable insights that complement scientific research. Contemporary extension systems recognize fishers not merely as recipients of information but as active partners in identifying problems, testing innovations, and developing locally appropriate solutions. Their participation significantly improves the relevance, adoption, and sustainability of extension interventions (Leeuwis & Aarts, 2021).

Fisheries extension personnel serve as the critical link between research institutions, policymakers, and fishing communities. Their role extends beyond the dissemination of technical information to include facilitation, capacity building, advisory support, and institutional development. Extension professionals organize training programmes, conduct demonstrations, strengthen producer organizations, and connect stakeholders with financial services, markets, and government schemes. In today's rapidly changing fisheries sector, effective extension personnel require strong communication skills, digital literacy, and the ability to facilitate collaborative learning processes among diverse stakeholders (Davis & Sulaiman, 2014).



Extension institutions provide the organizational foundation necessary for effective fisheries development. These institutions include government fisheries departments, research organizations, universities, training centres, non-governmental organizations, cooperatives, and private-sector agencies. They facilitate technology dissemination, capacity building, policy implementation, and market development while strengthening linkages between research and field-level application. Strong institutional coordination ensures that extension services remain accessible, responsive, and capable of addressing the evolving needs of fisheries stakeholders (FAO, 2022).

Extension Approaches in Fisheries

Over the years, fisheries extension has adopted different approaches to improve the effectiveness of advisory services and technology transfer. One of the earliest models was the top-down extension approach, where technologies and recommendations developed by researchers and policymakers were disseminated to fishers through formal extension systems. This approach played a significant role in accelerating technology diffusion and increasing production, particularly during the early phases of fisheries modernization. Government-led extension services, commodity-focused programmes, Training and Visit (T&V) systems, and project-based interventions are common examples of top-down approaches. While these models facilitated rapid dissemination of innovations, they often lacked flexibility and failed to adequately address local socio-economic and ecological conditions (Ragasa et al. 2016).

The limitations of centralized extension systems led to the emergence of bottom-up approaches that place fishing communities at the centre of the development process. These approaches emphasize participation, empowerment, and collaborative learning. Rather than receiving predetermined recommendations, fishers actively participate in identifying challenges, testing innovations, and evaluating outcomes. Participatory extension approaches have demonstrated considerable success in improving technology adoption, strengthening community ownership, and enhancing the sustainability of development interventions (Vidyawati & Jadoun, 2025).

Among the participatory approaches, the Farmers' Field School (FFS) model has gained considerable attention in fisheries and aquaculture development. The FFS approach encourages experiential learning through observation, experimentation, and group discussions. Participants develop technical knowledge, critical thinking abilities, and decision-making skills while gaining a deeper understanding of ecological processes affecting fisheries production. Studies have shown that FFS programmes significantly improve the adoption of sustainable



aquaculture practices, disease management strategies, and water quality management techniques (Quizon et al., 2001).

Similarly, the Farming Systems Research and Extension (FSR&E) approach views fisheries and aquaculture as components of broader livelihood systems. This approach integrates biological, social, economic, and environmental considerations to develop locally appropriate solutions. By addressing production challenges alongside household livelihood needs, FSR&E promotes sustainability, resilience, and long-term development outcomes, particularly among small-scale fishers and aquaculture producers (Chaubey et al., 2025)

Community-based extension approaches further strengthen collective action through cooperatives, self-help groups, producer organizations, and community institutions. These approaches enhance access to credit, inputs, markets, and information while empowering marginalized groups, including women and youth. Community participation not only improves livelihood security but also contributes to sustainable fisheries governance and resource management (FAO, 2022).

Fisheries Innovation Systems: A Modern Framework

Recent developments in extension theory have led to the emergence of Fisheries Innovation Systems (FIS), which provide a comprehensive framework for understanding how innovation occurs within fisheries and aquaculture sectors. Unlike traditional linear models of technology transfer, FIS recognizes that innovation results from continuous interactions among multiple stakeholders, including fishers, researchers, extension personnel, policymakers, financial institutions, input suppliers, and market actors. Knowledge flows in multiple directions, enabling stakeholders to collectively identify problems, develop solutions, and adapt innovations to local. The Fisheries Innovation System approach acknowledges that technological innovation alone is insufficient for sustainable development. Institutional, organizational, and social innovations are equally important in improving productivity, strengthening value chains, enhancing market access, and building resilience to environmental and economic shocks. Effective innovation systems rely on strong communication networks, trust among stakeholders, supportive policies, and coordinated institutional efforts. By fostering collaboration and learning, Fisheries Innovation Systems contribute significantly to sustainable fisheries development and climate resilience (Klerkx, 2020).



Conclusion

Fisheries extension has evolved from a simple technology transfer mechanism into a dynamic and participatory process that promotes learning, innovation, and sustainable development. Fishers, extension personnel, research institutions, government agencies, and private organizations all play essential roles in ensuring the success of extension programmes. While traditional top-down approaches contributed to rapid technology dissemination, modern fisheries extension increasingly emphasizes participation, stakeholder engagement, and systems thinking. The Fisheries Innovation System framework further highlights the importance of collaboration, knowledge exchange, and institutional coordination in addressing contemporary fisheries challenges. Strengthening these partnerships will be critical for enhancing productivity, improving livelihoods, and ensuring the long-term sustainability of fisheries and aquaculture sectors.

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Landscape Ecology and Insect Community Dynamics

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Abstract

Agricultural landscapes are complex ecosystems where interactions among crops, natural vegetation, insects, and environmental factors influence biodiversity and ecosystem functioning. Landscape ecology examines the spatial patterns and ecological processes operating across different habitats and their effects on biological communities. Insect community dynamics, including species diversity, abundance, distribution, and interactions, are strongly influenced by landscape composition and structure. Diverse landscapes containing natural habitats, hedgerows, flowering strips, and forest patches support greater populations of beneficial insects such as pollinators, predators, and parasitoids, thereby enhancing ecosystem services and contributing to sustainable pest management. Conversely, habitat fragmentation and agricultural intensification often reduce insect diversity and disrupt ecological balance, leading to increased pest outbreaks and reduced resilience of agroecosystems. Understanding landscape-level influences on insect communities is crucial for designing environmentally sustainable agricultural systems. This article discusses the principles of landscape ecology, factors affecting insect community dynamics, the role of habitat diversity in conservation biological control, and management strategies to promote beneficial insect populations in agroecosystems.

Keywords: Landscape Ecology, Insect Diversity, Agroecosystems, Biological Control, Habitat Management and Ecosystem Services.

Introduction: Insects are among the most diverse and ecologically important organisms on Earth. They play vital roles in pollination, nutrient cycling, decomposition, and biological control of pests. The distribution and abundance of insect populations are influenced not only by local habitat conditions but also by the broader landscape surrounding agricultural fields.



Landscape ecology is the study of interactions between spatial patterns and ecological processes across different scales. Modern agricultural intensification has transformed heterogeneous landscapes into simplified monocultures, reducing habitat diversity and negatively affecting insect populations. As a result, concerns about declining pollinator populations, increased pest outbreaks, and loss of biodiversity have gained global attention. Understanding how landscape structure influences insect communities can help develop sustainable agricultural practices that support biodiversity while maintaining crop productivity.

Landscape Ecology: An Overview

Landscape ecology focuses on the arrangement, composition, and connectivity of habitats within a landscape. Agricultural landscapes typically consist of crop fields, grasslands, forests, water bodies, hedgerows, and other semi-natural habitats.

Three important components of landscape ecology include:

- 1. Landscape Composition:** Refers to the types and proportions of different habitats present in a landscape. Diverse landscapes generally support higher insect diversity than uniform agricultural fields.
- 2. Landscape Configuration:** Describes the spatial arrangement and distribution of habitat patches. Connectivity among habitats facilitates movement, dispersal, and colonization of insects.
- 3. Landscape Connectivity:** Connectivity enables beneficial insects to move between natural habitats and crop fields, improving ecosystem stability and biological control services.

Insect Community Dynamics in Agricultural Landscapes

Insect community dynamics refer to changes in species composition, abundance, diversity, and interactions over time and space. These dynamics are influenced by several landscape-level factors.

Habitat Diversity: Heterogeneous landscapes provide food resources, nesting sites, and refuges for various insect species. Flowering plants offer nectar and pollen to pollinators and parasitoids, while natural vegetation provides shelter for predators. Studies have shown that farms surrounded by diverse vegetation often harbor higher populations of beneficial insects than farms located within extensive monoculture systems.



Habitat Fragmentation: Fragmentation occurs when large natural habitats are divided into smaller isolated patches. This process reduces species richness and limits movement of insects between habitats. Small and isolated populations are more vulnerable to local extinction due to environmental disturbances and reduced genetic diversity.

Agricultural Intensification: Excessive pesticide use, removal of field margins, and large-scale monoculture cultivation simplify landscapes and negatively affect insect biodiversity. Beneficial insects are often more sensitive to these disturbances than pest species, resulting in ecological imbalance.

Climate and Environmental Factors: Temperature, rainfall, humidity, and seasonal variations influence insect development, reproduction, and migration patterns. Climate change may alter insect distribution and community structure across landscapes.

Role of Landscape Ecology in Conservation Biological Control: Conservation biological control aims to enhance the effectiveness of naturally occurring predators and parasitoids by improving habitat conditions.

Landscape features that support biological control include:

- Flowering strips providing nectar and pollen resources.
- Hedgerows serving as refuges for predators and parasitoids.
- Forest patches supporting diverse insect communities.
- Cover crops that provide alternative hosts and prey.
- Reduced pesticide use to conserve natural enemies.

Research indicates that agricultural fields surrounded by semi-natural habitats experience greater pest suppression due to increased abundance of beneficial insects.

Ecosystem Services Provided by Insect Communities: Healthy insect communities contribute significantly to ecosystem functioning through:

Pollination: Many crops depend on insect pollinators for fruit and seed production. Diverse landscapes support a rich pollinator community and improve crop yields.

Biological Control: Predators and parasitoids naturally regulate pest populations, reducing the need for chemical pesticides.



Nutrient Cycling: Detritivorous insects contribute to decomposition and nutrient recycling within ecosystems.

Biodiversity Conservation; Insects serve as indicators of environmental health and play a key role in maintaining ecological balance.

Strategies for Enhancing Beneficial Insect Diversity: Several landscape management approaches can improve insect community dynamics:

1. Establish flowering field margins and buffer strips.
2. Maintain hedgerows and shelterbelts.
3. Preserve forest fragments and natural vegetation.
4. Promote crop diversification and intercropping.
5. Reduce indiscriminate pesticide applications.
6. Encourage ecological farming practices.
7. Improve habitat connectivity across agricultural landscapes.

These strategies not only conserve biodiversity but also strengthen ecosystem services essential for sustainable agriculture.

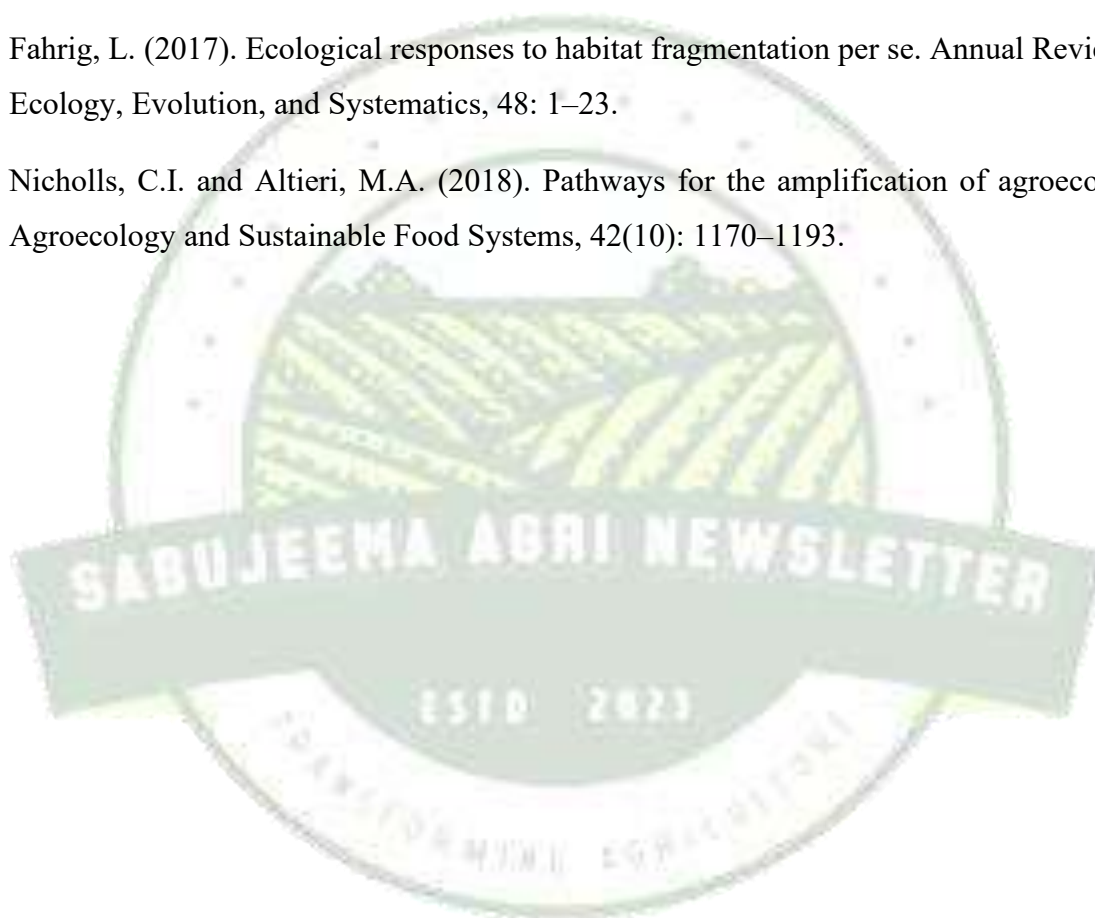
Conclusion: Landscape ecology provides valuable insights into the factors shaping insect community dynamics in agricultural ecosystems. Diverse and well-connected landscapes support beneficial insects, enhance biological control, improve pollination services, and increase ecosystem resilience. In contrast, habitat fragmentation and agricultural intensification often reduce biodiversity and disrupt ecological processes. Integrating landscape ecological principles into agricultural planning and management can promote sustainable crop production while conserving insect diversity. Future agricultural systems should focus on maintaining habitat heterogeneity and ecological connectivity to ensure long-term environmental sustainability and food security.

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Livelihood Analysis: Sustainability in Practice

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Introduction

The origins of livelihood analysis are rooted in agroecosystem analysis, pioneered by Gypmantasiri et al. (1980) and further developed by Conway (1985) at the University of Chiang Mai. As noted by Chambers (1992), this approach utilized bar diagrams to visualize village-level data, such as income sources and expenditure patterns. At its core, livelihood analysis examines stability, crisis management and the complexities of debt, credit, and relative income. In practice, this method recognizes that households engage in diverse, multiple activities (Chambers, 1992). By mapping data related to family demographics, financial status and crisis management across different social classes, this approach when facilitated effectively enables community members, including farmers in India and beyond, to actively participate in the analysis of their own living conditions.

The Concept of Livelihood Analysis

Livelihood analysis is the study of how living patterns diverge across social strata. It examines variables such as household size, housing quality, technology adoption, land ownership, income levels and sources, dietary habits, expenditure, debt, livestock ownership, migration, seasonality and strategies for coping with crises. The concept of sustainable livelihoods serves as a foundational reference point for development policy and planning. Definitions generally fall into two categories:

- **Narrow Economic Approach:** Focuses strictly on production, employment and household income.
- **Holistic Approach:** Integrates economic development with environmental sustainability and vulnerability reduction, while focusing on the inherent strengths of the rural poor.



The frameworks discussed here adopt this holistic perspective. While originally associated with rural development, these methodologies are equally applicable to urban livelihoods and the complex interactions between rural and urban economies. Modern livelihood frameworks draw from a rich history of development theory, including the integrated rural development planning (IRDP) of the 1970s, 1980s food security initiatives, Rapid Rural Appraisal (RRA), Participatory Rural Appraisal (PRA), farming systems research, gender analysis and evolving insights into poverty, well-being, risk assessment and agrarian reform.

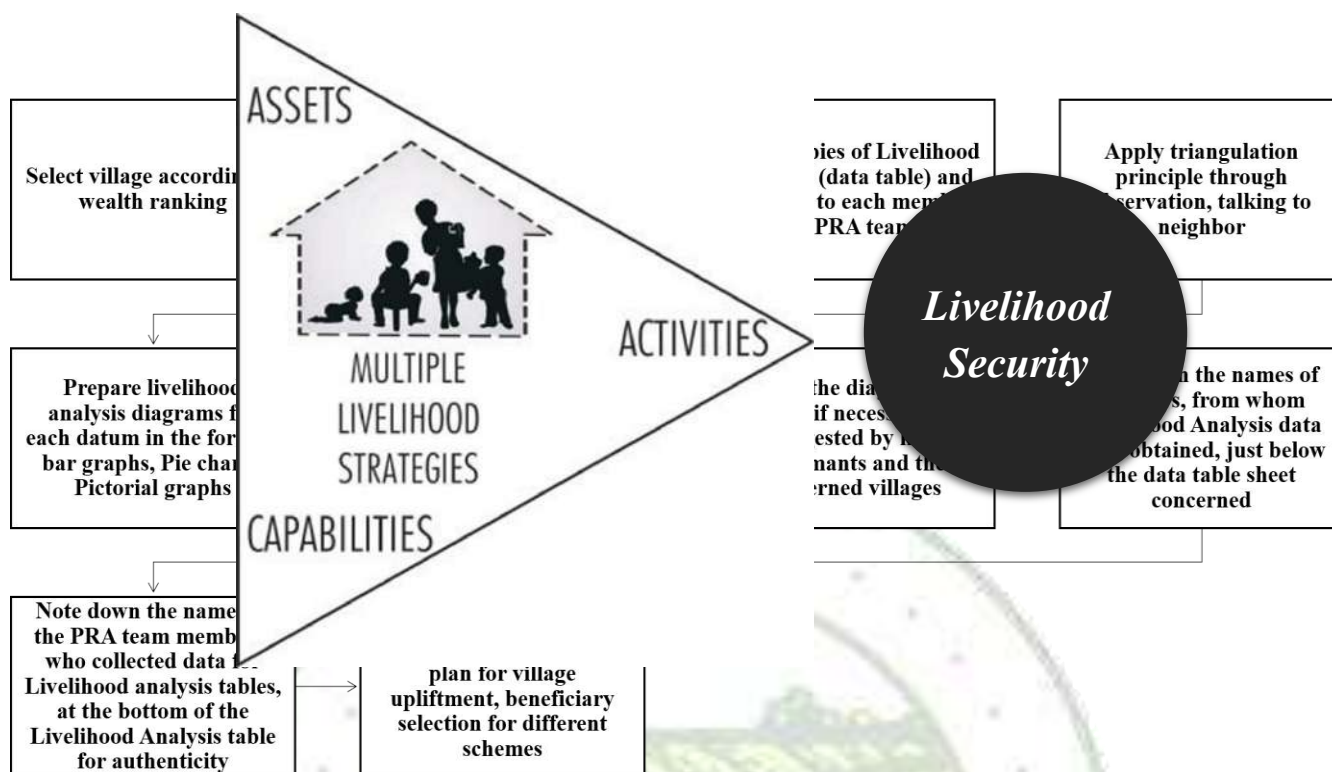
Critically, these frameworks evolved as a response to the flawed assumption that rural societies were homogenous and that households relied on single-purpose economies. Past development strategies often relied on narrow, sectoral, production-focused interventions that failed to account for the diverse, multi-faceted economic strategies employed by poor households. Consequently, the advent of participatory research has led to a more nuanced appreciation of how livelihoods are constructed and the various interconnected elements they comprise. Building on participatory research and the principles established by the World Commission on Environment and Development, Chambers and Conway formulated a foundational definition of livelihoods and sustainability in the early 1990s. Their work remains the cornerstone for all contemporary livelihood's frameworks.

“A livelihood comprises the capabilities, assets (stores, resources, claims and access) and activities required for a means of living: a livelihood is sustainable which can cope with and recover from stress and shocks, maintain and enhance its capabilities and assets, and provide sustainable livelihood opportunities for the next generation; and which contributes net benefits to other livelihoods at the local and global levels in the long and short term”

(Chambers and Conway, 1992)



Steps in analysis of livelihood (Swathilekshmi, CMFRI):



What is the livelihood framework

To navigate the complexities of livelihood analysis, it is essential to distinguish between a conceptual framework and a methodological approach. A framework serves as a lens for viewing the world, specifically helping us understand how households utilize their capabilities and assets to craft diverse livelihood strategies. It categorizes these assets and entitlements while mapping how local and global factors including various actors, institutions and processes influence livelihood security. Because frameworks are inherently subject to interpretation, refinement and varying nomenclature, this text seeks to demystify these core components by bridging the gap between theoretical models and practical application. Also debate exists regarding whether frameworks necessitate participatory methods, we prioritize the use of participatory research, appreciative inquiry and problem analysis as essential tools. Ultimately, the specific selection and combination of these methods remain flexible, allowing practitioners to adapt the framework to the unique needs of each situation.



Advantage of Livelihood Analysis

Adopting a livelihoods framework significantly enhances development work by providing a structured yet flexible roadmap that improves internal coherence, diagnostic precision and organizational learning. By prioritizing a holistic understanding of household strategies, this approach allows for more effective resource targeting, which increases project impact and helps staff cultivate relevant, community-aligned expertise. Furthermore, the framework gives actionable purpose to participatory methods by providing a clear structure for analysing data, while simultaneously facilitating cross-organizational partnerships through a shared analytical language. Ultimately, this approach improves an organization's ability to demonstrate clear, poverty-reducing outcomes making programs more attractive and complementary tool that strengthens rather than replaces existing development strategies.

Conclusion

In conclusion, livelihood analysis provides a robust, holistic framework that transcends narrow economic metrics by accounting for the diverse, multi-faceted strategies households employ to survive and thrive. By integrating participatory methods with a nuanced understanding of assets, capabilities and external environmental factors, this approach allows practitioners to move beyond outdated assumptions of rural homogeneity and better address the complexities of poverty and sustainability.

Ultimately, the power of this framework lies in its ability to transform raw data into actionable insights, fostering improved program design, resource targeting and organizational collaboration. As a versatile and complementary tool, it serves as a vital bridge between theoretical development models and real-world practice, enabling development actors to create more impactful, sustainable and community-centered interventions.

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From Field Research to Farmer's Empowerment: Promoting Sustainable Tea Cultivation in Uttarakhand through tea waste based biofertilizer

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Introduction

Tea is a widely recognized and popular beverage prepared from the leaves of *Camellia sinensis* (L.) O. Kuntze. The plant is an evergreen shrub. The infusion of tea leaves is packed with numerous health-promoting bioactive compound (Qin and Zhou et al., 2024). The major bioactive compounds include polyphenols, terpenoids, and alkaloids (Luo et al., 2024). These phytochemicals are well-documented for their antioxidant, anticancer, anti-inflammatory, and other pharmacological properties (Novilla et al., 2017; Vishnoi et al., 2018; Meng et al., 2019; Bortolini et al., 2021). The tea plant is a major cash crop of considerable economic significance, driving high demand in the global market (Xu et al., 2021). Despite being valuable, tea plant is highly susceptible to pest infestations and microbial infections. Conventional management practices rely heavily on synthetic agrochemicals in tea cultivation, which can increase the yield of tea leaves. However, their application often compromises tea quality (Pandey et al., 2021). The excessive and prolonged application of synthetic agrochemicals has been shown to reduce key bioactive constituents, particularly polyphenols, thereby diminishing the overall quality of the final product (Qiao et al., 2018).

Addressing the dual challenge of sustaining plant yield while preserving product quality, alternative cultivation strategies have gained prominence, with organic farming as one of the most promising approaches. An organic system includes biofertilizers, organic manures, biopesticides, and microbial inoculants (bacteria, fungi and algae). Organic manures serve as a



reservoir of nutrients (such as nitrogen, potassium, phosphorus, and organic matter) and release them gradually, reducing nutrient leaching and improving soil structure (Shaij et al., 2021). On the other hand, biopesticides are selective toxicants that bind to or interact with specific enzymes, receptors, proteins, or membrane components of pests, offering more environmentally compatible pest control (Casida 2009). Biofertilizers, in contrast to chemical fertilizers, comprise of living or latent microorganisms that enhance plant growth and soil fertility by increasing nutrient availability, synthesizing growth-promoting substances and improving plant resilience (Shahwar et al., 2023).

Tea plants thrive optimally in acidic soil with a pH range of 4.5-5.5 (Yan et al., 2020). Among beneficial microbes, arbuscular mycorrhiza fungi (AMF) i.e. endomycorrhizal fungi are particularly well suited to the acidic soil environment. These endomycorrhizal fungi readily colonize tea roots under acidic conditions and markedly improve nutrient-uptake efficiency (Singh et al., 2010). The extensive hyphal network of AMF extends beyond the root zone, enabling the plant to access water and nutrients that would otherwise remain unavailable, while simultaneously enhancing the water-holding capacity of soil (Liu et al., 2024). Consequently, AMF inoculation represents a biologically coherent and sustainable component of organic tea cultivation that supports both productivity and quality.

Project Funding and Training Program

A three-year research initiative (March 2023-May 2026) entitled “Promoting Himalayan tea cultivation through skill enhancement for livelihood support and land rehabilitation in hilly regions” funded by Govind Ballabh Pant National Institute of Himalayan Environment, MoEF & CC, Govt of India (Sanction No.-GBPI/ IERP/22-23/26/107), investigated the effect of modern sustainable tea cultivation practices using tea waste, suitable for Uttarakhand landscape. Central to the study was the application of a novel formulation based on mycorrhiza enriched tea waste manure (TWMGEU566) on tea plants at the different cultivation sites. Field trials demonstrated increased plant biomass (reflected in greater plant height, leaf number and shoot count) up to 23-36%, enriched phytochemical profiles (notably elevated polyphenols, alkaloids) up to 23-41%, and improved soil health. The bioinoculant encompassed favorable shifts in physicochemical parameters (pH, electrical conductivity, oxidation reduction potential, temperature and organic matter content) up to 18-54%, enhanced nutrient availability (nitrogen, potassium, and phosphorous) by 25%, and strengthened biological indicators (soil enzymatic activity and microbial load) up to 20-31%. Building on these encouraging results, a sequential series of training-cum-workshop was organized at three tea estates in Uttarakhand



to disseminate the improved tea cultivation practices and build local livelihood capacity. Three training-cum-workshop sessions were conducted at Champawat Tea Estate (District- Champawat, Uttarakhand) on 13th June 2025, followed by Berinag Tea Estate (District- Pithoragarh, Uttarakhand) and Ghorakhal Tea Estate (District-Nainital, Uttarakhand), on 18th and 19th February 2026 respectively.



Fig.1 Interaction with tea estate farmers on sustainable tea cultivation practices.



Fig. 2 Hands-on training of farmers on formulating biofertilizer at the tea estates.

Workshop Structure and Implementation

The workshop framework was focused on identifying major challenges which arise during the tea cultivation and discussing their effective solutions. The major gap observed was lack of awareness on diverse sustainable agricultural practices among farmers. Therefore, the knowledge and technical skill session was conducted to fill the gap and introduced them to a scientific approach to formulate mycorrhizae based biofertilizer using tea waste generated in tea estate's factory itself. The project team demonstrated the formulation of biofertilizer from



the tea waste, bagasse, vermicompost (procured from local market) and mycorrhiza (Procured from ICAR-PUSA, New Delhi), followed by the field application. The biofertilizer was applied by digging a trench of the 15-20 cm depth around the circumference of the plant root zone, followed by covering it with soil. The treated plants were subsequently labelled with name tags with date for identification.



Fig.3 Demonstration and implementation of biofertilizer on the field.

Certificate Distribution and Felicitation

The participation certificates were awarded to farmers and factory workers for their enthusiastic involvement. The resource person at respective tea estates were felicitated with a memento for acknowledging their support in the successful completion of training program.



Fig.4 Certificate distribution and felicitation



Conclusion

The interaction with farmers revealed the lack of awareness about the diverse methods of sustainable tea cultivation. The estates were following the ancient conventional practices, including employment of cow dung, and bone meal to cultivate the tea plants. The technology transfers during training-cum-workshop introduced a modern and organic approach for the better tea quality and yield. The work shop demonstrated improved understanding of how sustainable methods can enhance tea quality, reduce input cost, strengthen long-term viability and reduce dependency on synthetic agrochemicals. The adoption of sustainable organic agriculture practices, would improve soil health and enable tea growers to meet growing market demand for good quality tea and promote livelihood generation. The program has laid a strong foundation for continued knowledge sharing among farmers, and the gradual transition toward more resilient and ecofriendly tea production systems. By connecting scientific research with farmers training, and field level implementation, the program demonstrates how research based interventions can be translated into practical solutions for sustainable agriculture. Furthermore, regular monitoring, and follow-up training will be essential to sustain and introduce more advanced, cost effective and ecofriendly cultivation practices, achievable by government intervention through fundings and local community participation.

Acknowledgement: - The authors are grateful to Govind Ballabh Pant National Institute of Himalayan Environment- IERP, MoEF & CC, Govt of India and Graphic Era (Deemed to be University), Dehradun, Uttarakhand, for all the financial and technical support for the study.

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Microgreens: Tiny Greens, Mighty Nutrition

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Introduction

The post COVID-19 pandemic, increased the interest of growing and consuming fresh, healthy and functional foods, such as sprouted seeds and microgreens. Microgreens are the immature edible green plants mainly seedlings of vegetables, legumes or herbs harvested within 7 to 21 days after germination when the first true leaves appear. These are usually 2–8 cm in height and have intense sensory attributes, such as flavours, texture, aroma, appearance, and exotic colours, irrespective of their small expanse. They are widely used in salads, sandwiches, soups, and garnishing due to their attractive colours, delicate textures, and unique flavours and are increasingly recognized as next-generation superfoods or functional foods because they possess exceptionally high concentrations of health-promoting phytonutrients. Compared with their mature plant counterparts, microgreens often contain higher levels of antioxidants, vitamins, minerals, phenolic compounds, and other bioactive substances, making them a nutrient-dense food with significant potential to promote health and prevent disease. Interestingly it is so advantageous that their growth period is much shorter and their maintenance is considerably lower.

Nutrients

Microgreens are excellent sources of vitamins and minerals and phytochemicals. They are largely associated with vitamins A, C, E, K; micro and macro nutrients like Fe, Zn, N, P, K, Cu, Se, S, Mo, Mn, Ca etc. Apart from vitamins and minerals, they are rich in phytochemicals, which have immense potential to enhance human health and also to control diseases. Some of the major bioactive compounds such as ascorbic acid, phylloquinones, tocopherol, beta



carotene, phenolic antioxidants, carotenoids, anthocyanins, glucosinolates sugar content are present in large quantities. Several microgreens showed higher concentrations of antioxidants that can neutralize free radicals and help prevent damage caused by oxidative stress. Since microgreen are consumed fresh, loss of vit C due to cooking is minimal by preserving natural values and it functions as a potent water-soluble antioxidant essential for collagen synthesis, wound healing, immune function and iron absorption. Besides Vit C, Vit A and Vit E precursors present in microgreens contribute to vision, immune regulation, maintenance of epithelial tissue and antioxidant defence. Sugar levels in microgreens, primarily consisting of glucose, fructose, and sucrose, are relatively low. Organic compounds like anthocyanins and glucosinates present in microgreens are responsible for anti-inflammatory, anti-cancer and antiviral properties.

Cultivation

Microgreens are commonly produced from crops such as turnips, radishes, broccoli, cauliflower, carrots, celery, chard, lettuce, spinach, arugula, amaranth, cabbage, beets, parsley and basil. Commercially these are produced, both as soil and soilless substrate medium like cocopeat, vermiculite, peat, coconut coir dust etc. The cultivation of microgreens requires minimal space, less water, and a short growth period, making them suitable for urban farming, indoor gardening, and sustainable agriculture practices. The efficient growth of microgreens depends on quality and germination of seeds. Clean, high germination seeds free from chemical treatments can be used for its cultivation rather than regular seeds for household consumption. A regular planting pot or container with 4-5 inches deep with 3-4 inches of soil height can be taken and seeds are spread randomly on the soil surface without proper spacing. Light is a substantial factor which directly reflects the microgreen yield and nutritional composition. A bright window sill or a balcony that receives sunlight will be a good spot for cultivation of microgreens at small scale level. At least 3-4 hours of sunlight with regular watering enhances the growth. Sprinkle the water over the growing greens, twice a day. In 3-4 days time, small leaves grow over the soil with little shoots at the bottom. Once the plants are 2-3 inches taller, they are ready to be harvested. Microgreens contain cotyledons and hypocotyls when they are as young as 7 to 14 day seedlings harvested at right time, but differs from species to species. For harvesting, cut the microgreens with a pair of scissors or a sharp knife by holding them vertically, from just over the roots. Wash the harvested microgreens with cold running water and use it in a meal. Microgreens provide the best of nutrition when consumed fresh, right after the harvest. Dry them after washing and store in a paper wrap in the refrigerator. As the



cultivation time is shorter, there are no major pest attacks microbial contamination occurs due to careless practises such as sowing of denser seeds, contaminated irrigation water and external environmental factors. Due to the perishable characteristics, it is very important that the harvested microgreens have to be subjected to post harvesting techniques to enhance the shelf life by maintaining the respiration rates and avoiding any possible contamination. Generally, post-harvest techniques like washing, drying, freezing, microwaving and mild chemical treatments are done inorder to maintain their phytochemical content and overall nutritional value even after few days of harvesting.

Health Benefits

Microgreens with high density of nutrients, minerals and phytochemicals are reported for improving some chronic disorders and their efficacies in reducing diseases. These are suggested with high potential to reduce diabetes. The hypoglycaemic effect and anti-diabetic regulation have shown by broccoli and fenugreek microgreens respectively. Barley microgreens improved glucose metabolism and reported to exhibit reduction of sperm morphological defects and chromosomal aberrations in comparison to untreated animals. Microgreens cultivated in low potassium salt hydroponic systems are recommended to patients with chronic kidney disorders who are advised restricted intake of high potassium content foods. It is recommended as a functional food for cancer, obese and chronic heart disease patients. These are also reported to reduce lipid and cholesterol levels in cardiovascular disease patients. The root extracts of licorice microgreen contain high anti- inflammatory polyphenols and reduced inflammatory markers. Fenugreek microgreens have higher levels of iron, with high level of bio-accessibility to the cells and hence can be recommended to young children, pregnant women and old aged people.

Biofortification

Biofortification, ie increased micro or mineral concentrations can enhance the nutritional value of crops and enables more stable dietary levels of these nutrients. The total ascorbic acid and vitamin C levels increased significantly in arugula microgreens through irrigation with ascorbic acid solutions. Ingestion of such biofortified microgreens could meet the daily vitamin C requirements of people. Iron enrichment can be done by fortification of different vegetables like spinach and pea microgreens. Other microelements can also be enhanced through biofortification.



Conclusion and Future Perspectives

Microgreens, a new plant based functional food harvested 7-14 days of sowing are rich sources of nutrients, minerals and phytochemicals which impart high antioxidants and other medicinal effects due to which it can be considered as a practical food to tackle many diseases and disorders. The wide diversity of microgreen species provides consumers with a broad spectrum of nutritional and therapeutic benefits. However, further evidence-based research is needed to optimize production systems, enhance yield, improve post-harvest handling and shelf life, minimize microbial contamination, develop effective biofortification strategies, and explore the role of microgreens in personalized nutrition and precision medicine.





Mitigation of Enteric Methane Emissions in Large Ruminants: Integrating Nutritional, Genetic, and Management Interventions

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Introduction

Enteric methane emission from ruminant livestock has emerged as a major environmental concern due to its strong contribution to climate change and its association with inefficiencies in animal production systems. Methane (CH₄), a potent greenhouse gas (GHG) with 28 times higher global warming potential than carbon dioxide (CO₂), contributes approximately 16 per cent of global GHG emissions, largely sourced from ruminant enteric fermentation. Recent advances in mitigating enteric methane emissions have focused mainly on integrating nutrition, genetic, and technological innovations. Several feed additives have demonstrated considerable potential in reducing methane (CH₄) emissions from livestock, including 3-nitrooxypropanol (3-NOP), seaweed, nitrates, biochar, and various phytochemicals. These compounds work primarily by suppressing methanogenesis or by altering the availability of hydrogen within the rumen, thereby limiting the conditions that favour methane production. In parallel, selective breeding programmes targeting animals with naturally low methane output have revealed a heritable component to emissions, opening the door to long-term genetic mitigation strategies. At the molecular level, advanced biotechnological approaches, particularly CRISPR/Cas-based gene editing systems, are being explored to directly interfere with methanogenic pathways in both ruminant microbiomes and feed plants. Complementing these biological and nutritional strategies, a range of engineering-driven solutions is also gaining traction, including methane-capturing masks and backpacks



worn by animals, cryogenic purification techniques, and systems designed to recover and convert captured methane into bioenergy. Together, these diverse approaches represent a multifaceted effort to address enteric methane emissions across nutritional, genetic, biotechnological, and technological fronts.

Keywords: Methane emission, Ruminants, Feed additives, Phytochemicals, Technological innovations.

Introduction

Methane (CH₄) is a colourless, odourless, highly flammable hydrocarbon gas having an approximately 12-year atmospheric lifetime and 28 times higher global warming potential (GWP) than CO₂ over 100 years. It accounts for approximately 16% of global greenhouse gas emissions, ranking second only to CO₂ in terms of total radiative forcing (IPCC, 2021). In agriculture, where paddy fields contribute around 8 per cent to global anthropogenic CH₄ production, livestock particularly ruminants and manure management produces approximately 32 per cent of total anthropogenic methane (FAO, 2023; Nature, 2021). In ruminants, CH₄ is expelled predominantly through eructation, accounting for approximately 95–98% of total emissions, with only a minor fraction (2–5%) released via flatulence. Ruminant enteric emission account for approximately 115 million tonnes of CH₄ annually (IEA, 2021). Samal *et al.* (2024) reported that enteric fermentation from Indian livestock generated approximately 11.63 Tg of methane per year, based on updated country-specific emission factors and the latest livestock census, while overall methane emissions from the livestock sector increased to 12.74 Tg yr⁻¹ after accounting for emissions from manure management. Beyond climate change, methane emissions also represent a direct loss of feed energy, approximately 2–12% of gross energy intake (Johnson & Johnson, 1995). Therefore, strategies that mitigate CH₄ production not only have environmental benefits but can also improve feed efficiency and animal productivity, aligning with the principles of sustainable livestock farming.

Biochemistry and pathways of enteric methane production

The ruminant digestive system is uniquely adapted to process fibrous plant material through microbial fermentation. Rumen is an anaerobic fermentation chamber that harbours a complex microbial community, including bacteria, bacteriophages, protozoa, and fungi, where carbohydrates are degraded into volatile fatty acids (VFAs; acetate, propionate, and butyrate), gases (CO₂, CH₄, and H₂), and microbial biomass. The fermentation reactions can be summarized as:



- $\text{Glucose} + 2 \text{H}_2\text{O} \rightarrow 2 \text{Acetate} + 2 \text{CO}_2 + 8 \text{H}_2$
- $\text{Glucose} + 4 \text{H}_2 \rightarrow 2 \text{Propionate} + 2 \text{H}_2\text{O}$
- $\text{Glucose} \rightarrow \text{Butyrate} + 2 \text{CO}_2 + 4 \text{H}_2$

Produced hydrogen must be removed to prevent inhibition of microbial metabolism, which is achieved predominantly through methanogenesis, a process mediated by **methanogenic archaea** that utilize CO_2 and H_2 as substrates to produce methane: $\text{CO}_2 + 4 \text{H}_2 \rightarrow \text{CH}_4 + 2 \text{H}_2\text{O}$.

Methanogenesis in the rumen is primarily driven by archaea of the genus *Methanobrevibacter*, notably *M. ruminantium* and *M. gottschalkii* (Hook *et al.*, 2010). Methanogens employ several metabolic pathways, including the **hydrogenotrophic pathway** that converts CO_2 to CH_4 using H_2 (the most common pathway), the **methylotrophic pathway**, which utilizes methyl compounds such as methanol or methylamines and the **acetoclastic pathway** which splits acetate into CH_4 and CO_2 . The **methyl-coenzyme M reductase (MCR)** enzyme catalyses the final step in methanogenesis, converting methyl-coenzyme M ($\text{CH}_3\text{-S-CoM}$) and coenzyme B (HS-CoB) into CH_4 . Where the production of acetate and butyrate is accompanied by the formation of hydrogen in rumen, the production of propionate is associated with utilisation of ruminal hydrogen, suggesting diversion of enteric fermentation towards more propionic acid production can also be an alternative to reduce enteric methane production.

Genetic basis and heritability of methane emissions

Methane emissions in ruminant livestock demonstrate moderate heritability, with published estimates ranging from 0.12 to 0.52, underscoring the feasibility of achieving meaningful genetic progress through selective breeding programs (Manzanilla-Pech *et al.*, 2021). Genetic correlations between methane yield and feed efficiency traits most notably residual feed intake (RFI) is consistently positive yet modest in magnitude, indicating that concurrent improvement of enteric methane output and feed utilization efficiency is biologically plausible within structured breeding objectives. At the genomic level, genome-wide association studies have successfully identified quantitative trait loci (QTL) and single-nucleotide polymorphisms (SNPs) associated with rumen microbial community composition and methane yield, providing a molecular basis for marker-assisted selection strategies (Hayes *et al.*, 2016). Nevertheless, host genetics represents only one component of a multifactorial regulatory framework governing enteric methane production. Additional determinants of considerable importance



include dietary composition particularly the ratio of structural to non-structural carbohydrates, rumen fermentation pH, voluntary dry matter intake, and the rate of digesta passage through the reticulorumen, each of which modulates the metabolic activity of methanogenic archaea and the availability of hydrogen substrate within the rumen environment.

Strategies of methane mitigation

Global initiatives such as the Global Methane Pledge (2021) and the United Nations Sustainable Development Goals (SDG 13 -Climate Action) emphasise methane reduction as a top priority for climate stabilisation. Achieving a 30% reduction in global methane emissions by 2030 is critical to limiting the temperature rise to below 1.5°C (United Nations Environment Programme; UNEP, 2022). For the livestock industry, this challenge has translated into an urgent demand for **methane-smart livestock systems** that integrate nutritional, genetic, and technological innovations to reduce emissions per unit of animal product.

Nutritional approach

Nutritional interventions are among the most widely studied and immediately applicable strategies for mitigating enteric methane (CH₄) emissions. The underlying principle is to alter rumen fermentation pathways either by decreasing hydrogen (H₂) availability for methanogenesis or by redirecting H₂ toward alternative sinks such as propionate formation or nitrate reduction.

Feed additives with direct anti-methanogenic action

3-Nitrooxypropanol (3-NOP)

3-Nitrooxypropanol (3-NOP) is the most thoroughly researched chemical inhibitor of enteric methane production. It acts by irreversibly inhibiting methyl-coenzyme M reductase (MCR), which is the terminal enzyme in the methanogenesis pathway (Duin *et al.*, 2016). When 3-NOP binds to the MCR enzyme's active site, it oxidises the Ni (I) cofactor to Ni (II), rendering the enzyme inactive and blocking CH₄ synthesis. However, effects vary depending on diet composition and delivery method. The additive is now approved for commercial use in Brazil, Chile, and the European Union (Yu *et al.*, 2021). The large-scale commercial adoption of 3-nitrooxypropanol marks an important advance in industrial methane mitigation, as research has consistently shown long-term reductions of about 25-40% in enteric methane emissions under practical production conditions (Hristov *et al.*, 2015; Beauchemin *et al.*, 2020).



Study	Animal system	Experimental scale	Methane reduction (%)	Duration/ conditions	Key remarks
Hristov <i>et al.</i> (2015)	Dairy cattle	Commercially relevant herd trials	~30	Long-term feeding under production conditions	Sustained methane reduction without adverse effects on feed intake or milk yield
Beauchemin <i>et al.</i> (2020)	Dairy and beef cattle	Review of multi-study datasets	20–40	Across diets and management systems	Confirms consistency and scalability of 3-NOP for industrial applications
Yu <i>et al.</i> (2021)	Ruminants	Meta-analysis and controlled trials	~30 (mean)	Dose- and diet-dependent	Highlights robust mitigation efficacy and mode of action
Dijkstra <i>et al.</i> (2018)	Beef cattle and dairy cows	Long-term feeding experiment	20-44	Continuous supplementation	Demonstrated persistent inhibition of ruminal methanogenesis

Halogenated Methane Analogues

Halogenated CH₄ analogues such as bromoform, bromochloromethane (BCM) and chloroform exert their anti-methanogenic activity through direct inhibition of the MCR enzyme via



covalent binding to its prosthetic group, coenzyme F₄₃₀, thereby disrupting the terminal catalytic step of archaeal methanogenesis (Roque *et al.*, 2021). The discovery that certain red macroalgae, most notably *Asparagopsis taxiformis*, naturally biosynthesize bromoform as a secondary metabolite has provided a compelling biological basis for investigating macroalgal dietary supplementation as a methane mitigation strategy (Li *et al.*, 2025). In vitro studies show up to 98% CH₄ reduction (Machado *et al.*, 2014) while in vivo trials demonstrate significant reductions (40-80%) without adverse effects on milk or meat composition (Kinley *et al.*, 2020; Roque *et al.*, 2021). However, bromoform trace (6-35 µg/L) was reported (Muizelaar, 2021), which is far below the safe oral exposure limit (0.02 mg/kg of BW/day defined by USEPA, 2017). At the regulatory level, feed additive preparations derived from *A. taxiformis* have been granted Generally Recognized as Safe (GRAS) status in the United States (Blue Ocean Barns, 2021).

Nitrate as an Alternative Hydrogen Sink

Nitrate (NO₃⁻) serves as a competitive sink for ruminal H₂, diverting it from methanogenesis by converting NO₃⁻ to ammonia (NH₃) through microbial reduction. However, improper adaptation may lead to nitrite (NO₂⁻) accumulation, causing methemoglobinemia and reduced oxygen transport in blood. Additionally, NO can be produced from absorbed NO₂, which can reduce blood pressure. Encapsulation technologies and gradual adaptation protocols have been developed to mitigate toxicity risks (Lee *et al.*, 2017).

Biochar

Biochar, a highly porous carbon material produced via pyrolysis of biomass, has recently emerged as a sustainable feed additive. Its physical structure increases ruminal surface area, improves microbial habitat and adsorbs gases potentially reducing CH₄ formation (Ayeneshet & Temesgen, 2025)

Feed Additives with Indirect Methane Suppression

Ionophores

Ionophores such as **monensin** selectively inhibit gram-positive bacteria, shifting ruminal fermentation toward propionate formation. However, recent studies show no suppression of gm (+ve) bacterial population and no methane reduction (Melchior *et al.*, 2018). Moreover, due to antimicrobial resistance concerns, the European Union has banned ionophores for long-term use in livestock.



Direct-Fed Microbials (DFM)

Probiotics or DFM such as *Saccharomyces cerevisiae* (SC) and *Propionibacterium freudenreichii* can stabilise rumen pH, enhance propionate formation and indirectly lower CH₄ intensity (Phesatcha *et al.*, 2021). Supplementation can improve fibre digestibility and milk yield but exhibits inconsistent CH₄ outcomes (Chen *et al.*, 2020; Jeyanathan *et al.*, 2019). While some in vitro studies show up to **20% CH₄ reduction**, in vivo trials often find no significant difference (Meller *et al.*, 2019). Continued exploration of strain specificity and host-microbiome interactions is warranted.

Phytochemicals

Plant-derived secondary metabolites collectively termed **phytochemicals** have received substantial attention as natural alternatives to synthetic anti-methanogenic feed additives. These compounds, including **tannins**, **saponins**, **flavonoids** and **essential oils**, exhibit bioactive properties that can modify rumen microbial activity, suppress methanogens, and redirect fermentation toward more energetically efficient pathways. Because of their plant origin, phytogenic feed additives (PFAs) are perceived as safe, eco-friendly and compatible with organic livestock production standards.

Tannins

Tannins are polyphenolic compounds broadly categorized into condensed tannins (CT) and hydrolysable tannins (HT). Their capacity to reduce enteric methane production stems principally from their ability to bind proteinaceous constituents of methanogen cell walls and to interfere with interspecies hydrogen transfer between protozoa and methanogenic archaea (Ku-Vera *et al.*, 2020). Beyond these indirect effects, tannins have also been identified as direct inhibitors of methanogen activity (Aboagye & Beauchemin, 2019). When incorporated into CT-rich diets at appropriate inclusion levels, methane mitigation can be achieved without detrimental effects on dry matter intake or live weight performance.

Essential Oils (EOs)

Essential oils (EOs) are volatile mixtures of terpenes and phenylpropanoids extracted from plants. Their strong lipophilic properties allow them to disrupt microbial membranes and enzyme systems. EOs exhibit broad-spectrum antimicrobial activity, targeting both bacteria and archaea. By reducing the abundance of hydrogenotrophic methanogens and protozoa, they



can suppress CH₄ formation (Ku-Vera *et al.*, 2020). Importantly, essential oils have no known safety risks for animals or human consumers and are recognised as safe for commercial use.

Commercial Phytogenic Products

India's ICAR-NIANP has developed two notable anti-methanogenic feed formulations; Harit Dhara and Tamarin Plus, comprising of tannins, saponins, and selected essential oils. Harit Dhara has demonstrated enteric CH₄ reductions of approximately 20%, with cost-benefit ratios of 1:5 in growing cattle and buffalo calves, 1:3 in lactating cattle and buffalo, and 1:4 in sheep (Patent No. 201941004992, 2019). Methlow, a phytogenic mixture developed at ICAR-IVRI, has shown methane suppression of 30.37% under in vitro conditions and 14.9% in in vivo trials. Collectively, these plant-based formulations represent among the few commercially viable, phytogenic methane inhibitors validated for on-farm application under tropical production systems.

Global Genetic Initiatives

Programs such as **“Project Cool Cows”** in the UK and **DairyBio Australia** are pioneering methane-efficient breeding strategies. The Cool Cows project, led by Paragon Vets, Semex, and Scotland's Rural College (SRUC), achieved the first successful birth of a selectively bred low-methane calf “Hilda” in December 2024. Hilda's historic birth combines three efficient steps, including the prediction of a low-emission heifer by DNA analysis, oocyte collection, and IVF using sex-sorted sperm, which potentially paved the way for the creation of a low-emission cow herd. Some estimates suggest that this approach could reduce enteric methane emissions from cattle by approximately 50% annually, potentially contributing to a cumulative reduction exceeding 20% by 2050 a substantially greater rate of progress compared to conventional selection methods, which have historically achieved only a 1% annual reduction in methane emissions.

Biotechnological Innovations

In recent years, biotechnology has emerged as one of the most transformative tools in agricultural science. Beyond nutrition-based mitigation, researchers are now exploring genetic and molecular interventions that directly target methane synthesis pathways in both forage crops and methanogenic archaea. The convergence of CRISPR/Cas-based genome editing, metabolic engineering, and synthetic biology offers a novel paradigm for achieving heritable, long-lasting reductions in methane emissions (Zhao *et al.*, 2025).



Technological Innovations

Methane-Capture Mask

The Zero Emission Livestock Project (ZELP), a United Kingdom-based initiative established in 2019 (Project ID: 877091), developed a wearable catalytic device fitted over the muzzle of cattle to capture exhaled methane at the point of emission. Exhaled air is directed through a miniaturized oxidation chamber coated with a proprietary metal catalyst, facilitating the conversion of CH_4 into CO_2 and water vapour. The device further integrates Internet of Things (IoT) technology, incorporating lateral sensors that continuously measure gas flow, CH_4 concentration, and breathing rate. Collected data are transmitted wirelessly via Bluetooth or Wi-Fi to cloud-based dashboards linked to a farm management application, enabling precision livestock management functions such as real-time health monitoring, and correlation of feed efficiency with individual methane output. This mask weighs <500g with no stress to animals; comply to five freedoms and has won the prestigious ‘**Terra cart design**’ in the UK, 2022.

Cow fart backpack

It is an innovative approach to capture and utilise methane emitted by cattle through flatulence, thereby mitigating its impact on climate change. A lightweight plastic bag is attached to the cow's back and connected via a tube to its digestive system. The flatulence, which primarily consists of methane and small amounts of carbon dioxide, is collected and stored in the bag instead of escaping into the air. A valve in the tube prevents backflow of collected gas. This can then be purified and used as a renewable biogas source for cooking, lighting, or power generation. This dual-purpose solution not only prevents methane from contributing to global warming but also reduces human dependence on fossil fuels and conventional biofuels, promoting a sustainable and eco-friendly energy alternative. Such technologies hold great potential in countries like India, where the large cattle population could become a valuable resource for green energy production while simultaneously helping to curb climate change (Sharma *et al.*, 2012).

Cryogenic Methane Purification System

Cryogenic technology aims to condense and purify CH_4 from barn air using extreme cooling. By using the concept of boiling point, methane can be purified through sequential separation of gases. A two-stage cryogenic trap for dairy respiration chambers was tested by Pethani *et al.* (2024). Barn air enters Cooler 1 (-120 to -140 °C), where CO_2 solidifies; residual gas flows



into Cooler 2 (-160 to -180 °C), forming a CH₄ + O₂ liquid mixture. Gentle reheating releases O₂ first, leaving purified liquid CH₄ collected in a storage vessel. By carefully warming the second stage, O₂ was vaporised first, leaving high-purity liquid CH₄. In that study, ~92% of emitted CH₄ was captured, yielding ~90% pure liquid methane (Pethani et al., 2024). Such cryogenic systems are energy-intensive, but they demonstrate that biomethane can be recovered from dilute cattle emissions (which are normally <0.1% CH₄ in barn air). With further development, cryogenic capture could turn a waste emission into a usable biofuel.

Conclusion

Effective mitigation of enteric methane emissions necessitates a multifaceted strategy that synergistically integrates nutritional, genetic, and technological interventions. Sustainable approaches encompassing targeted feed additives, selective breeding programmes, and emerging biotechnologies collectively offer viable pathways to reduce methane intensity without compromising animal productivity. Ultimately, the adoption of a holistic, climate-smart livestock management framework will be indispensable to reconcile ruminant production systems with global methane reduction commitments and long-term environmental sustainability objectives.

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Moringa: The Miracle Tree for Milk, Money, and Marginal Farmers' Prosperity

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Introduction

Livestock production plays a crucial role in ensuring food security, nutritional security, and livelihood generation for millions of rural households. However, the availability of quality feed and fodder remains a major constraint affecting animal productivity, particularly in developing countries. Conventional feed ingredients are becoming increasingly expensive, creating a need for alternative, nutritious, and locally available feed resources. In this context, Moringa (*Moringa oleifera*), popularly known as the drumstick tree or miracle tree, has emerged as a promising fodder resource due to its exceptional nutritional value, rapid growth, and adaptability to diverse agro-climatic conditions.

Nutritional Composition of Moringa Leaves

Moringa leaves are highly nutritious and contain a rich concentration of proteins, vitamins, minerals, and antioxidants. The leaves typically contain:

- Crude protein: 20–30%
- Crude fiber: 10–15%
- Calcium: 2.0–3.5%
- Potassium: 1.0–1.5%
- Iron, zinc, and selenium in appreciable quantities
- Vitamins A, B-complex, C, and E
- Essential amino acids such as methionine, lysine, and threonine





The proteins present in moringa leaf are similar to conventional protein-rich feeds like soybean meal. The rich presence of essential amino acids such as lysine, methionine, and tryptophan, which are crucial for overall metabolic functions in animals. The high protein content makes moringa leaves comparable to many conventional protein supplements used in livestock feeding. The fibers of moringa leaf maintains the gastro-intestinal wellbeing. The higher levels of calcium, phosphorus, iron and vitamin A, B, C etc. in Moringa leaves enhance lactation performance as well as improves milk quality.

Benefits of Moringa Leaves in Livestock Feeding

1. Improves Growth Performance

The high-quality protein and balanced amino acid profile of moringa leaves support better growth rates in calves, goats, sheep, poultry, and pigs. Supplementation with moringa leaf meal has been reported to improve body weight gain and feed conversion efficiency.

2. Enhances Milk Production

Moringa leaves are considered a natural galactagogue. Feeding moringa foliage to dairy animals increases milk yield due to its rich protein, mineral, and vitamin content. Studies have also shown improvements in milk fat and protein percentages.

3. Improves Reproductive Performance

Adequate nutrition is essential for reproductive efficiency. Moringa leaves provide important micronutrients and antioxidants that support hormonal balance, fertility, conception rate, and overall reproductive health in livestock.

4. Strengthens Immunity

Moringa leaves contain antioxidants such as flavonoids, phenolic compounds, vitamin C, and vitamin E that enhance immune function. Animals receiving moringa supplementation often exhibit improved disease resistance and better overall health.

5. Reduces Feed Cost

Moringa can be cultivated on farms with minimal inputs and harvested multiple times throughout the year. Its use as a locally available protein source can partially replace expensive commercial concentrates, thereby reducing feeding costs.



6. Improves Digestibility

The tender leaves are highly palatable and digestible. Supplementation improves nutrient utilization and rumen microbial activity, leading to enhanced feed efficiency in ruminants.

7. Supports Climate-Resilient Livestock Production

Moringa is drought tolerant and can thrive under harsh environmental conditions. Its year-round availability provides a reliable fodder source during periods of feed scarcity, making livestock systems more resilient to climate variability.

Use of Moringa in Different Livestock Species

Dairy Cattle and Buffaloes

- Can be fed as fresh fodder, dried leaf meal, or silage additive.
- Improves milk yield and milk quality.
- Enhances body condition and reproductive performance.

Goats and Sheep

- Highly palatable and readily consumed.
- Promotes growth and weight gain.
- Suitable as a protein supplement during dry seasons.

Poultry

- Moringa leaf meal can be incorporated into poultry rations at 5–10%.
- Improves growth, egg production, yolk pigmentation, and immunity.



Pigs

- Serves as an economical protein source.
- Supports growth performance and feed efficiency.

Rabbits

- Enhances growth rate and reproductive performance.
- Improves health status due to its antioxidant properties.

Methods of Feeding

Moringa leaves can be utilized in several forms:

1. Fresh green fodder
2. Dried leaf meal
3. Leaf powder incorporated into concentrate mixtures
4. Silage mixed with other fodder crops
5. Complete feed blocks and total mixed rations



To avoid digestive disturbances, gradual introduction and balanced supplementation are recommended.

Constraints and Precautions

Although moringa is highly beneficial, certain precautions should be followed:

- Excessive feeding may reduce feed intake due to high fiber content.
- Leaves should be harvested at the appropriate stage for optimum nutrient quality.
- Proper drying and storage are necessary to prevent nutrient losses.
- Moringa should supplement rather than completely replace balanced livestock diets.

Conclusion

Moringa oleifera is a valuable, sustainable, and cost-effective feed resource for livestock production. Its high protein content, rich mineral composition, antioxidant properties, high fiber content and year-round availability make it an excellent supplement for improving animal



growth, milk production, reproductive performance, and health. Promotion of moringa cultivation and utilization in livestock feeding can contribute significantly to enhancing productivity, reducing feed costs, and strengthening climate-resilient livestock systems, particularly among smallholder farmers and resource poor women farmers. It is truly a miracle plant that addresses milk, money and marginal farmer's livelihood.





Air Layering in Grapevines: A Rapid and Farmer-Friendly Technique for Multiplication of Quality Planting Material

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Introduction

Grapevine (*Vitis* spp.) is one of the most important fruit crops cultivated worldwide for table purposes, raisin production, juice extraction, and wine making. The success of a vineyard largely depends upon the availability of healthy, true-to-type, and vigorous planting material. Traditionally, grapevines are propagated through hardwood cuttings, a method that has been practiced successfully for many years. However, the production of planting material through hardwood cuttings is often time-consuming and may require 1.5 to 2 years before a well-established plant becomes ready for field planting.

With increasing demand for quality planting material and the need for rapid multiplication of elite cultivars and rootstocks, alternative propagation techniques are gaining importance. Air layering is one such technique that offers a practical and efficient method for producing rooted grapevine plants directly on the mother plant. The technique enables the development of roots while the shoot remains attached to the parent vine, thereby ensuring a continuous supply of water and nutrients until sufficient rooting has occurred. Air layering can significantly reduce the time required for the multiplication of grapevine plants and can be adopted by farmers, nursery operators, and researchers for the rapid propagation of desirable cultivars and rootstocks.

Why Air Layering in Grapevines?

The conventional hardwood cutting method involves the collection of cuttings, rooting under nursery conditions, transplanting, and subsequent establishment in the field. This process requires considerable time, labour, and management.



Air layering offers several advantages:

1. Faster Multiplication
2. Higher Survival Rate
3. True-to-Type Plants
4. Utilization of Vineyard Suckers
5. Additional Income Opportunity
6. Reduced Nursery Period
7. Materials Required

The following materials are required for air layering: Sharp grafting or budding knife, secateurs, Indole-3-butyric acid (IBA) solution at 3000 ppm, Cotton swabs, Moist sphagnum moss, Transparent polythene sheets (200 gauge), Thread or plastic ties, growing bags and Suitable potting media.

Experimental Procedure

Selection of Mother Plants: The work may be conducted on:

1. Six to seven-month-old grapevine rootstocks planted at a spacing of 3.0 m × 1.8 m, or
2. Healthy suckers arising from established vineyards.

Healthy, disease-free, and vigorous plants should be selected for the study. Proper cultural practices must be followed throughout the experimental period.

Grafting of Desired Variety

Well-matured, healthy, and pencil-thick active shoots of the desired grape variety should be selected for grafting onto suitable rootstocks. After successful graft union formation, healthy and vigorously growing grafts should be identified and selected for air layering. The selected vines should be maintained under recommended vineyard management practices.

Selection of Shoots for Air Layering

After successful graft establishment, healthy and vigorous vines or suckers should be selected for air layering. The selected shoots should be pencil-thick, actively growing, and possess healthy foliage with 7 to 8 well-developed nodes and an average internodal distance of 6 to 7



cm. The use of vigorous shoots is important, as they generally exhibit better rooting potential and produce healthier rooted layers.

Girdling Operation

A ring of bark approximately 2 cm wide should be completely removed from the selected shoot. The girdling should be performed between two nodes, at approximately 10 cm above ground level, using a sharp and clean knife as shown in Fig 1.

Care must be taken to remove the bark completely without causing injury to the woody portion of the stem. The removal of bark interrupts the downward movement of carbohydrates and growth-promoting substances. Consequently, these compounds accumulate above the girdled region and promote root initiation.



Fig 1. Girdling and Wrapping of Air Layers.

Application of Rooting Hormone

Indole-3-butyric acid (IBA) at 3000 ppm (recommended) should be applied to the girdled portion. The hormone solution can be applied using a cotton swab to ensure uniform coverage. IBA promotes early root initiation, an increased number of roots, improved root length, and better root quality.

Wrapping of Air Layers

After the application of IBA, the girdled portion is covered with moist sphagnum moss to provide a favourable environment for root initiation. The moss is then wrapped securely with a transparent polythene sheet (200 gauge) and tied firmly at both ends to prevent moisture loss. This wrapping helps maintain adequate humidity around the girdled area, promoting root



development. The transparent polythene also allows easy observation of root formation without disturbing the developing roots.

Observation of Root Formation

After 20-30 days, roots begin to emerge within the sphagnum moss. Root development can be observed through the transparent polythene wrapping. The layer should be allowed to remain attached until a sufficient root system develops. A well-developed root system improves survival after detachment.



Fig 2. Rooting of the Air layer after removing transparent polythene sheet

Detachment of Rooted Layers

Once adequate rooting is achieved, like Fig 2, the rooted layer should be detached from the mother plant. A clean cut should be made just below the rooted portion using secateurs. Care should be taken not to damage the newly formed roots.

Post-Detachment Handling

Immediately after detachment, the rooted layers should be shifted to a shaded location. The polythene wrapper should be removed carefully. The sphagnum moss should remain



undisturbed around the roots. Excessive handling may damage delicate roots and reduce survival.



Fig 3. Transplanting of air layers into growing bags.

Nursery Establishment

The rooted air layers should be planted in growing bags containing suitable growing media as shown in Fig 3. A recommended growing medium may consist of soil, sand, and Well-decomposed farmyard manure or cocopeat. The nursery plants should be maintained under partial shade initially and gradually acclimatized to field conditions. Regular irrigation should be provided to encourage root establishment.





Fig 4. Plants after 20 days of transplanting.

Scope and Economic Significance

Air layering provides grape growers with a simple and economical method for rapid multiplication of superior cultivars and rootstocks. Vineyard suckers, which are normally removed during desuckering, can be utilized for propagation, reducing wastage and producing additional planting material. The technique can help farmers establish small nurseries, reduce dependence on external sources, and generate additional income through the sale of rooted plants. Owing to its low cost, minimal investment, and ease of adoption, air layering has considerable potential for commercial and on-farm grapevine propagation.

Conclusion

Air layering represents a simple, economical, and effective technique for rapid multiplication of grapevines. By allowing root formation while the shoot remains attached to the mother plant, the method enhances rooting success and reduces the time required for plant production. The technique can be particularly valuable for multiplying elite cultivars, rootstocks, and vineyard suckers that are otherwise discarded. Adoption of air layering by grape growers can facilitate faster production of quality planting material, reduce dependence on conventional propagation systems, and create additional opportunities for income generation through nursery plant production. Thus, air layering has considerable potential as a supplementary propagation method for sustainable grapevine cultivation and nursery development.



Smart and Sustainable Textiles: Green Innovations Shaping the Future of Apparel

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Abstract

The textile and apparel industry is undergoing a significant transformation as it seeks to address growing concerns related to environmental degradation, resource depletion, and climate change. Traditional textile production processes are often associated with high water and energy consumption, chemical pollution, and substantial waste generation, necessitating the adoption of more sustainable and innovative approaches. In this context, smart and sustainable textiles have emerged as a promising solution that combines environmental responsibility with technological advancement.

Smart and sustainable textiles integrate eco-friendly materials, resource-efficient manufacturing processes, renewable energy technologies, and intelligent functionalities to create apparel that is both environmentally sustainable and technologically advanced. Innovations such as biodegradable and bio-based fibres, recycled textiles, natural dyes, water-saving processing techniques, energy-harvesting fabrics, solar-powered textiles, and wearable sensing technologies are reshaping the future of the fashion and textile sector. These developments not only reduce the ecological footprint of textile production but also enhance product functionality, consumer comfort, and overall quality of life.

India, as one of the world's leading textile producers, is actively embracing sustainable practices through circular fashion models, textile recycling initiatives, cleaner production technologies, and the promotion of renewable and eco-friendly fibres. Supported by government initiatives and industry-led innovations, the sector is increasingly aligning with global sustainability goals and climate resilience strategies.



This article explores the emerging landscape of smart and sustainable textiles and highlights how green innovations, renewable energy integration, and advanced technologies are driving the transition towards a more sustainable apparel industry. By examining recent developments and future possibilities, the article underscores the potential of smart textiles to contribute to environmental sustainability, resource efficiency, and a greener future for the global fashion ecosystem.

Keywords: Smart textiles, Sustainable textiles, Green innovation, Renewable energy, Circular fashion, Textile sustainability, Emerging technologies, Eco-friendly apparel.

INTRODUCTION

The textile and apparel industry is one of the largest manufacturing sectors in the world, playing a vital role in economic development, employment generation, and global trade. However, it is also among the most resource-intensive industries, consuming enormous quantities of water, energy, and chemicals while generating significant amounts of waste and greenhouse gas emissions. The rise of fast fashion has further intensified concerns regarding environmental degradation, resource depletion, and unsustainable consumption patterns. As consumers become increasingly aware of the environmental footprint of their clothing choices, the demand for sustainable and responsible fashion solutions continues to grow.

In response to these challenges, the textile sector is undergoing a remarkable transformation driven by green innovations, renewable energy integration, and emerging technologies. Smart and sustainable textiles are emerging as a promising solution that combines environmental responsibility with technological advancement. These next-generation textiles are designed not only to reduce environmental impact through the use of eco-friendly materials and cleaner production processes but also to provide advanced functionalities such as energy harvesting, health monitoring, temperature regulation, and enhanced user comfort.

Sustainable textiles are increasingly being developed from renewable, biodegradable, and recycled resources such as organic cotton, hemp, bamboo, banana fibre, recycled polyester, and other bio-based materials. Simultaneously, innovative manufacturing approaches including digital printing, natural dyeing, water-efficient processing, enzymatic treatments, and zero-liquid discharge technologies are helping to reduce resource consumption and environmental pollution. These advancements are contributing to a more circular and resource-efficient textile ecosystem.



A particularly exciting development is the emergence of smart textiles that integrate electronics, sensors, conductive materials, and renewable energy technologies into fabrics. Imagine a garment capable of monitoring health parameters, regulating body temperature, detecting environmental conditions, or even generating electricity from sunlight and human movement. Such innovations are transforming clothing from passive materials into intelligent systems capable of enhancing quality of life while supporting sustainability goals.

India, as one of the world's leading textile producers, is uniquely positioned to contribute to this transition. The country's long-standing tradition of reuse, repair, and repurposing textiles reflects the principles of circularity that are now being embraced globally. Historically, garments in Indian households were used for extended periods and repeatedly transformed into new products, minimizing waste and maximizing resource utilization. Today, this cultural legacy is being strengthened through modern initiatives promoting sustainable fibres, recycling technologies, circular fashion models, and cleaner production practices.

Recognizing the importance of sustainability, the Government of India has launched several initiatives to encourage environmentally responsible textile production and consumption. Efforts to promote sustainable raw materials, resource-efficient manufacturing, waste reduction, renewable energy adoption, and circular economy practices are helping the industry align with national climate commitments and global sustainability standards. These measures are expected to enhance competitiveness, attract investment, and support India's vision of becoming a global leader in sustainable textile manufacturing.

As the world seeks innovative solutions to address climate change, environmental degradation, and resource scarcity, smart and sustainable textiles offer a compelling pathway toward a greener future. By integrating sustainability principles with cutting-edge technologies, the textile and apparel sector is evolving from a traditional manufacturing industry into a key driver of environmental stewardship, renewable energy utilization, and technological innovation. This article explores the latest developments in smart and sustainable textiles and highlights how these green innovations are shaping the future of apparel and contributing to a more resilient and sustainable world.

What Are Smart Textiles?

Imagine wearing a shirt that can monitor your heart rate, a jacket that charges your mobile phone using sunlight, or sportswear that adjusts its temperature according to your body's needs.



These futuristic concepts are no longer confined to science fiction. They are becoming a reality through the development of smart textiles.

Smart textiles, also known as intelligent or e-textiles, are fabrics that can sense, respond, and adapt to changes in their environment or the wearer's condition. Unlike conventional fabrics that serve primarily as passive materials, smart textiles are designed to perform additional functions through the integration of advanced materials, sensors, electronics, and digital technologies.

These innovative textiles can respond to various stimuli such as temperature, pressure, light, moisture, movement, or physiological signals from the human body. Depending on their design, smart textiles may monitor health conditions, regulate body temperature, provide protection from environmental hazards, generate energy, or even communicate data in real time.

The development of smart textiles represents a remarkable convergence of textile science, electronics, material engineering, and digital technology. Advances in fields such as the Internet of Things (IoT), artificial intelligence (AI), wearable electronics, and nanotechnology have accelerated the growth of smart textile applications across healthcare, sports, defence, transportation, and fashion industries.

One of the most exciting aspects of smart textiles is their ability to enhance both functionality and sustainability. For example, energy-harvesting fabrics can convert solar energy or body movement into electricity, reducing dependence on conventional power sources. Similarly, smart garments capable of monitoring health parameters can support preventive healthcare and improve quality of life.

Smart textiles are generally classified into three categories. Passive smart textiles can sense environmental changes, active smart textiles can sense and respond to those changes, while very smart textiles can sense, react, and adapt their behaviour automatically. This progression reflects the growing sophistication of textile technologies and their expanding role in everyday life.

As consumers increasingly seek products that combine comfort, convenience, sustainability, and technological innovation, smart textiles are emerging as a transformative force in the apparel sector. By turning ordinary fabrics into interactive and intelligent materials, these



innovations are redefining the future of clothing and paving the way for a more connected, sustainable, and technology-driven world.

What Are Sustainable Textiles?

Sustainable textiles are materials that are designed, produced, used, and disposed of in ways that minimize environmental impact while promoting social and economic responsibility. These textiles are typically manufactured using renewable, biodegradable, recycled, or low-impact raw materials and are produced through resource-efficient processes that conserve water, energy, and chemicals. The goal of sustainable textiles is to meet present needs without compromising the ability of future generations to meet their own needs.

Sustainable textile production also focuses on reducing water consumption, energy use, chemical inputs, and waste generation. Innovations such as natural dyes, digital printing, enzymatic processing, water recycling systems, and circular production models are helping to make textile manufacturing more environmentally responsible. These approaches contribute to the conservation of natural resources while reducing pollution and greenhouse gas emissions.

The true potential of innovation lies in the convergence of smartness and sustainability. Modern textile technologies are increasingly being designed to address both performance and environmental objectives simultaneously. For example, solar-powered fabrics can capture renewable energy from sunlight, while energy-harvesting textiles can convert body movement or heat into usable electrical energy. Similarly, self-cleaning and temperature-regulating fabrics can reduce the need for frequent washing and excessive energy consumption, thereby lowering the overall environmental footprint of clothing.

Smart and sustainable textiles are also supporting the transition towards a circular economy by promoting durability, resource efficiency, and waste reduction. By extending garment life, improving product functionality, and enabling innovative recycling solutions, these textiles contribute to more responsible patterns of production and consumption.

As the world seeks solutions to climate change, resource scarcity, and environmental degradation, smart and sustainable textiles are emerging as a powerful example of how technology and sustainability can work together. By integrating intelligent functionalities with eco-friendly materials and green manufacturing practices, these innovative textiles are reshaping the future of apparel and paving the way for a more sustainable, resilient, and technologically advanced fashion industry.



Green Innovations Transforming the Apparel Sector

The apparel industry is undergoing a remarkable transformation as sustainability becomes a central focus of innovation. For decades, the sector has been associated with intensive resource consumption, environmental pollution, and growing volumes of textile waste. Today, however, advances in science, technology, and sustainable design are creating new opportunities to reduce the industry's environmental footprint while improving product performance and consumer experiences. Green innovations are reshaping the way textiles are produced, used, and recycled, paving the way for a more sustainable future.

Sustainable Fibres for a Greener Future

One of the most significant developments in sustainable fashion is the growing use of eco-friendly fibres derived from renewable and biodegradable resources. Traditional textile fibres are increasingly being supplemented or replaced by alternatives such as organic cotton, hemp, bamboo, banana fibre, pineapple leaf fibre, and regenerated cellulosic fibres. These materials generally require fewer chemical inputs and can have a lower environmental impact compared to conventional fibres.

Researchers and manufacturers are also exploring innovative bio-based materials derived from algae, agricultural residues, and even fungal mycelium. Such alternatives not only reduce dependence on non-renewable resources but also create opportunities for utilizing agricultural waste that would otherwise be discarded.

Circular Fashion and Textile Recycling

The concept of circular fashion is gaining momentum as the industry seeks to move away from the traditional "take-make-dispose" model. Recycling technologies now enable discarded textiles and plastic waste to be transformed into valuable raw materials for new products. Recycled polyester made from used plastic bottles, regenerated fibres from textile waste, and upcycled fashion products are becoming increasingly common.

Many brands are also encouraging consumers to return used garments for recycling or resale, helping to extend product lifecycles and reduce landfill waste. These initiatives support a circular economy in which resources remain in use for as long as possible, minimizing environmental impact and promoting responsible consumption.



Water-Saving and Cleaner Production Technologies

Textile manufacturing is traditionally one of the most water-intensive industrial processes. Green innovations are helping address this challenge through the adoption of water-efficient technologies and cleaner production methods.

Digital printing technologies, for example, significantly reduce water and chemical usage compared to conventional printing processes. Natural dyes derived from plants and other renewable sources are gaining popularity as environmentally friendly alternatives to synthetic dyes. Similarly, enzymatic treatments are replacing some chemical-intensive processing methods, reducing pollution and energy consumption.

Advanced wastewater treatment systems, including Zero Liquid Discharge (ZLD) technologies, are enabling textile industries to recycle and reuse water, thereby minimizing environmental contamination and conserving valuable water resources.

Renewable Energy and Energy-Harvesting Textiles

One of the most exciting developments in smart textiles is their ability to generate and utilize renewable energy.

Researchers have developed solar-powered fabrics capable of capturing sunlight and converting it into electricity. These textiles can potentially power wearable electronics, sensors, and communication devices without relying solely on conventional batteries.

Similarly, energy-harvesting textiles are being designed to convert body movement, mechanical vibrations, and body heat into usable electrical energy. Technologies such as piezoelectric, triboelectric, and thermoelectric fibres are enabling garments to function as miniature power generators.

Imagine a future where a jacket charges a mobile phone while its wearer walks outdoors or where sportswear powers fitness-tracking devices through body movement. Such innovations demonstrate how apparel can contribute to renewable energy generation while enhancing user convenience.

Smart Textiles for Health and Well-Being

The healthcare sector represents one of the most promising application areas for smart textiles.



Wearable garments embedded with sensors can continuously monitor physiological parameters such as heart rate, body temperature, respiration, and physical activity. These textiles enable real-time health monitoring without compromising comfort or mobility.

Smart healthcare textiles have potential applications in:

- Elderly care
- Remote patient monitoring
- Sports performance assessment
- Rehabilitation programmes
- Occupational health and safety

By providing continuous health data, these garments support preventive healthcare and enable early detection of potential health issues.

Self-Cleaning and Temperature-Regulating Fabrics

Advances in nanotechnology and material science have enabled the development of self-cleaning and adaptive textiles.

Inspired by natural phenomena such as the lotus leaf effect, self-cleaning fabrics repel dirt, water, and stains, reducing the need for frequent washing. This contributes to significant savings in water, energy, and detergent use throughout a garment's lifespan.

Temperature-regulating textiles represent another important innovation. These fabrics can respond to changing environmental conditions by improving thermal comfort and reducing dependence on external heating or cooling systems. Such capabilities are particularly valuable in regions experiencing increasing temperature variability due to climate change.

Digital Technologies Driving Sustainable Fashion

Emerging technologies such as artificial intelligence (AI), machine learning, and digital design tools are helping the apparel industry become more efficient and sustainable. AI-driven forecasting systems can predict consumer demand more accurately, reducing overproduction and excess inventory. Digital sampling and virtual prototyping allow designers to create and test products without producing multiple physical samples, thereby minimizing material waste.



Three-dimensional knitting and automated manufacturing technologies further support sustainable production by reducing fabric waste and enabling on-demand manufacturing tailored to consumer needs

Emerging digital technologies are accelerating sustainability throughout the apparel value chain.

Artificial Intelligence (AI)

AI is helping fashion companies improve demand forecasting, optimize inventory management, and reduce overproduction. By predicting consumer preferences more accurately, AI minimizes waste associated with unsold products.

Internet of Things (IoT)

IoT-enabled garments can communicate with connected devices, providing real-time information related to health, performance, and environmental conditions. Such technologies enhance functionality while creating opportunities for personalized consumer experiences.

3D Knitting and Digital Manufacturing

Digital manufacturing technologies enable precise production processes that significantly reduce material waste. Three-dimensional knitting systems can create entire garments with minimal cutting and sewing, thereby improving resource efficiency and reducing production waste.

India's Journey Towards Sustainable Textiles

India has a long tradition of sustainable textile practices rooted in reuse, repair, and resource conservation. Historically, garments were used for extended periods and repeatedly repurposed into new products, reflecting principles of circularity that are now gaining global attention.

Today, India is actively promoting sustainable textile production through the adoption of eco-friendly fibres, cleaner technologies, and circular business models. Government initiatives, industry collaborations, and research institutions are supporting the transition towards a greener textile sector.

The increasing adoption of renewable energy, wastewater recycling systems, sustainable dyeing technologies, and textile recycling initiatives is helping the Indian textile industry align with global sustainability goals while enhancing its competitiveness in international markets.



Several textile clusters across India have adopted sustainable manufacturing practices, including wastewater recycling, renewable energy integration, and circular production models. Initiatives such as Project SU.RE and the InTex India Programme are encouraging industries to embrace sustainability and strengthen India's position as a global hub for responsible textile production.

Challenges and Future Opportunities

Despite significant progress, several challenges remain in the widespread adoption of smart and sustainable textiles.

These include:

- High production costs
- Limited consumer awareness
- Scalability constraints
- Recycling complexities
- Durability of smart textile components
- Infrastructure requirements

However, continuous advances in material science, digital technologies, renewable energy systems, and circular economy models are expected to overcome many of these barriers in the coming years.

Future innovations may include:

- Fully biodegradable smart garments
- Energy-positive clothing
- AI-enabled adaptive apparel
- Digital product passports
- Carbon-neutral textile manufacturing
- Smart textiles integrated with renewable energy systems

These developments have the potential to revolutionize the apparel industry and contribute significantly to global sustainability goals.



Conclusion

Smart and sustainable textiles represent a powerful fusion of innovation, technology, and environmental responsibility. By integrating renewable materials, circular production practices, advanced digital technologies, and intelligent functionalities, these textiles are transforming the apparel industry into a more sustainable and resilient sector.

From energy-generating fabrics and self-cleaning garments to biodegradable fibres and AI-driven manufacturing systems, green innovations are redefining what clothing can do and how it can contribute to environmental stewardship. As industries and consumers increasingly prioritize sustainability, smart and sustainable textiles are poised to play a critical role in addressing global challenges related to climate change, resource conservation, and sustainable development.

The apparel of the future will be more than just fashionable—it will be intelligent, resource-efficient, environmentally responsible, and capable of supporting a greener and more sustainable world.

As the boundaries between fashion, technology, and sustainability continue to blur, smart and sustainable textiles are poised to become a cornerstone of future apparel systems. By embracing green innovation today, the textile industry can help build a future that is not only technologically advanced but also environmentally resilient and socially responsible.

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PRECISION FARMING: A PATHWAY TO CLIMATE RESILIENT TO AGRICULTURE

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Abstract

By 2050, it is anticipated that there will be nine billion people on the planet, making agriculture crucial to meeting the rising demand for food while tackling environmental issues. However, agriculture's capacity to meet these demands is being weakened by elements including biodiversity loss, decreased carbon storage in soils and vegetation, soil degradation, pollution, desertification, and the depletion of water and energy resources, all of which are exacerbated by climate change.

The term "precision agriculture" (PA) describes data-driven agricultural management techniques that try to lessen their negative effects on the environment. These include GPS, GIS, sensors, drones, Variable Rate Technology (VRT), and data analytics that are tailored to specific agroecological regions to manage field variability and maximise input utilisation for improved, profitable, efficient, sustainable, and intelligent crop and livestock farming.





Components of Precision Agriculture

- **Geographic Information Systems (GIS) and Global Positioning Systems (GPS):** These technologies make it easier to map field features like soil type, elevation, yield variability, and management zone delineation. Farmers can make targeted input selections by superimposing different spatial layers, increasing sustainability and efficiency.
- **Remote and Proximal Sensing:** Continuous monitoring of crop growth, soil moisture, and nutrient status is made possible by remote sensing technologies using satellites, UAVs (drones), and multispectral cameras. Early detection of crop stress and disease is made possible by vegetation indexes like the Normalised Difference Vegetation Index (NDVI). For aerial or satellite data, proximal sensors—such as portable or tractor-mounted devices—offer ground truth validation.
- **IoT sensors:** In addition to controlling water and fertiliser through site-specific farm management, IoT sensors enable real-time monitoring of soil moisture and nutrient levels. Granular data on variables like pest pressure and nutrient levels is recorded by IoT sensors (weather stations, soil moisture) and put straight into AI models to produce real-time alerts.
- **Technology with variable rates:** One of the main uses of PA is VRT, which uses equipment that uses spatial data maps to automatically modify the rates at which inputs like seeds, fertilisers, herbicides, and other chemicals are applied. Within the CSA framework, VRT contributes to the low emissions or mitigation pillar by minimising input waste and nitrogen losses, supports the resilience or adaptation pillar through predictive analytics that enable in-season adjustments to climate and yield variability, and increases yields and improves nutrient-use efficiency.
- **Robotics and unmanned aerial vehicles:** UAVs are being used more and more for precise spraying, pest monitoring, and crop reconnaissance. Robots carry out labour-intensive or repetitive jobs like mechanical sowing and weeding. These developments improve operational safety and lower labour expenses.



Resilience to Climate Change

By offering early alerts for stressful situations, precision agriculture technology improve adaptive ability. Farmers may anticipate and manage climate risks with the use of yield forecasting, weather-linked irrigation, and predictive pest alarms. Precision farming thus serves as a technique for both adaptation and mitigation.

Climate Resilience Integration

Combining remote sensing fusion with GIS and precision agriculture techniques can successfully develop a system for resistance against the effects of climate change. Research shows that using GIS systems to analyse remote sensing data spatiotemporally is effective in forecasting and mitigating the effects of extreme weather events, such as heat waves, floods, and droughts. Effective early warning systems that benefit agricultural regions are made possible by the convergence of GIS mapping of flood-prone areas with satellite monitoring of soil water content and active rainfall. By combining IoT-based weather stations with automated watering systems, farmers were able to achieve sustainable agricultural results in inclement weather.

Adaptation: Increasing Climate Variability Resilience

- Drought resilience: Compared to flood irrigation, precision irrigation systems use 30–50% less water, guaranteeing agricultural production viability in areas with limited water resources.
- Heat stress management: Timely management responses, such as modifying planting dates, choosing heat-tolerant cultivars, or turning on cooling irrigation at crucial reproductive phases, are made possible by real-time temperature monitoring and predictive agro-meteorological models.



- Flood and waterlogging management: Waterlogging-prone areas are identified using high-resolution digital elevation models (DEMs) and drainage monitoring devices, allowing for focused drainage improvements that lower agricultural losses.
- Crop variety optimisation: By matching crop genotypes to site-specific soil and climate profiles, AI-driven variety selection systems maximise performance in local conditions that are expected to alter due to climate change.

Mitigation: Cutting GHG Emissions from Agriculture

- Nitrogen management: Excess nitrogen that would otherwise be lost as nitrous oxide (N₂O), a greenhouse gas 298 times more potent than CO₂ over a century, is reduced through site-specific nitrogen administration guided by soil sensing and crop modelling.
- Decreased integration of tillage: Optimal tillage choices, such as minimum-till and no-till systems that store carbon in soil organic matter, are supported by precision soil data. Adoption of conservation agriculture on 180 million hectares worldwide already sequesters about 0.9 GtCO₂e annually.
- Optimised fuel usage: Telematics systems optimise field logistics and machinery scheduling, while GPS-guided auto-steering reduces fuel consumption by 10–15% by eliminating overlapping passes.
- Carbon farming and soil carbon monitoring: Under developing voluntary carbon markets, carbon credit quantification is supported by precise mapping of soil organic carbon (SOC) utilising proximate sensors and satellite-based modelling.

Difficulties and Obstacles in Adoption of precision a

Despite their potential, a number of obstacles prevent precision agriculture technology from being widely used.

1. High Initial Investment: Analytics systems, drones, and sensors can be expensive. Upfront expenses are more than quick gains for smallholders. This obstacle might be lessened by shared service or leasing models.
2. Data Management and Connectivity Gaps: Internet infrastructure is lacking in many rural areas. To guarantee inclusion, offline or hybrid solutions are required.



3. **Limited Technical Skills:** To properly analyse digital data, farmers need training. Insufficient capacity building puts technology at risk of underutilisation.
4. **Interoperability Problems:** Integration is hampered by the absence of standardisation among various platforms and devices.
5. **Policy and Regulatory Uncertainty:** In the administration of digital agriculture, data privacy, ownership, and intellectual property rights continue to be murky areas.

Suggestions for Policy and Prospects

- **Improving Access and Infrastructure**

Governments need to make investments in data platforms, inexpensive IoT devices, and rural connectivity. Through shared service models, collaborations between cooperatives and agritech businesses can increase accessibility.

- **Encouraging Localisation and Research**

Localising technologies for various agroecological zones and smallholder situations should be the main emphasis of research institutions. Partnerships between the public and commercial sectors can lower costs and increase innovation.

- **Services for Extension and Capacity Building**

To encourage use, digital training modules and demonstration plots should be included in agricultural extension programs. Innovation can be stimulated by youth involvement in agri-tech entrepreneurship.

- **Interoperability and Data Governance**

Clearly define your data ownership, privacy, and sharing policies. Open-data platforms safeguard agricultural interests while fostering innovation.

- **Climate-Smart Integration**

Programs for climate adaptation and mitigation that incorporate precision agriculture

Conclusion

A revolutionary approach to crop production that is both climate resilient and sustainable is precision agriculture. By combining IoT, remote sensing, drones, smart irrigation, and analytics, farmers can make adaptable, well-informed decisions that boost yields while



ISSN:3107-4200

SABUJEEMA

Agri Newsletter

An International Newsletter for Agriculture and Allied Sciences



minimising resource loss and environmental damage. But achieving these advantages calls for a comprehensive strategy that incorporates financial assistance, policy alignment, technical innovation, and capacity training.



Volume 3 - Issue 03 (June-August) 2026



Protecting the Golden Power of Turmeric: How Simple Blanching Can Improve Turmeric Powder Quality

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Abstract

Turmeric (*Curcuma longa* L.) is popularly known as the "Golden Spice of India" and has been an integral part of Indian kitchens and traditional medicine for centuries. Besides imparting a characteristic yellow colour and flavour to food, turmeric is widely recognized for its medicinal properties. It has long been used in Ayurveda for wound healing, improving digestion, boosting immunity, and managing various health disorders.

The medicinal value of turmeric is mainly attributed to curcumin, a naturally occurring bioactive compound that possesses powerful antioxidant, anti-inflammatory, antimicrobial, and therapeutic properties. Due to its numerous health benefits, curcumin has attracted significant attention from researchers, pharmaceutical industries, and health-conscious consumers worldwide.

Why Does Turmeric Quality Matter?

The demand for turmeric and turmeric-based products is continuously increasing in both domestic and international markets. However, the quality of turmeric powder depends not only on the variety cultivated but also on the processing methods adopted after harvest.

Traditionally, turmeric rhizomes undergo curing, drying, and grinding before being converted into powder. While these operations are necessary for storage and marketing, they can also cause losses of valuable compounds such as curcumin and essential oils. As a result, the final turmeric powder may contain lower levels of beneficial constituents than the fresh rhizomes.



Therefore, developing processing methods that preserve these bioactive compounds has become increasingly important for producing premium-quality turmeric powder.

Curcumin: The Most Valuable Component of Turmeric

Curcumin is the principal pigment responsible for the characteristic yellow colour of turmeric. More importantly, it is the compound responsible for many of turmeric's medicinal properties.

Scientific studies have shown that curcumin exhibits antioxidant, anti-inflammatory, anticancer, antimicrobial, and immune-enhancing activities. Because of these health-promoting effects, turmeric powder with higher curcumin content is considered more valuable for food, pharmaceutical, nutraceutical, and herbal industries.

Unfortunately, curcumin can be affected by improper processing conditions. Excessive heating during curing may lead to degradation and reduction of curcumin content, ultimately lowering the quality and medicinal value of the final product.

The Challenge of Traditional Processing

Many traditional processing methods focus primarily on improving appearance, drying efficiency, and storage life. However, these methods may unintentionally reduce the concentration of important phytochemicals present in turmeric.

Apart from curcumin, turmeric contains several beneficial compounds including polyphenols, flavonoids, alkaloids, tannins, oleoresins, and essential oils. These compounds contribute to the antioxidant capacity, aroma, flavour, colour, and therapeutic properties of turmeric.

Losses of these compounds during processing can reduce the overall nutritional and medicinal quality of turmeric powder. Therefore, there is a need for scientific interventions that help retain these valuable constituents.

Blanching: A Simple Solution

Blanching is a short-duration heat treatment in which fresh plant materials are exposed to hot water or steam for a specific period. This process is widely used in the food industry to improve product quality and preserve important nutrients.

Researchers have explored different pre-treatment methods to determine their effects on turmeric powder quality. Among the various treatments evaluated, blanching turmeric rhizomes at $90^{\circ}\text{C} \pm 2^{\circ}\text{C}$ for five minutes was found to be particularly effective.



This simple treatment provided significant improvements in both the chemical and physical quality of the turmeric powder while minimizing the loss of valuable bioactive compounds.



How Blanching Helps Preserve Curcumin

One of the most important findings of the study was the improved retention of curcumin in turmeric powder prepared from blanched rhizomes.

The controlled blanching treatment helps in reducing undesirable enzymatic activity that may contribute to the degradation of curcumin during subsequent processing. As a result, more curcumin is retained in the final product, thereby enhancing its medicinal and nutritional value.

Higher curcumin retention is especially beneficial for consumers seeking health-promoting food products and for industries manufacturing turmeric-based health supplements and herbal medicines.

Retention of Other Beneficial Compounds

The advantages of blanching extend beyond curcumin preservation. The treatment also helps retain several other important phytochemicals present in turmeric.

Polyphenols and flavonoids, which are known for their strong antioxidant activity, were better preserved in blanched samples. Similarly, alkaloids and tannins, which contribute to various biological activities, showed improved retention.



The study also revealed higher retention of oleoresins and essential oils, which are responsible for the characteristic aroma and flavour of turmeric. Consequently, the resulting turmeric powder possessed improved sensory quality and enhanced consumer appeal.

Improvement in Physical and Sensory Quality

In addition to preserving beneficial compounds, blanching had a positive influence on the physical and sensory characteristics of turmeric powder.

Turmeric powder prepared from blanched rhizomes exhibited improved colour, aroma, texture, and overall acceptability. Since consumers often judge product quality based on appearance and fragrance, these improvements can significantly enhance market value.

The retention of natural pigments and aromatic compounds also contributes to a more attractive and superior-quality product.

Benefits for Farmers and Processing Industries

The adoption of scientific pre-treatment techniques such as blanching can provide several advantages throughout the turmeric value chain.

Farmers can benefit from the production of higher-quality raw materials, while processors can manufacture turmeric powder with superior nutritional and medicinal attributes. Better product quality can increase consumer confidence, improve market competitiveness, and potentially fetch premium prices.

As the demand for functional foods and natural health products continues to rise globally, producing turmeric powder with higher curcumin content can create new opportunities for value addition and export promotion.

Future Scope

With growing awareness regarding the health benefits of turmeric, consumers are increasingly seeking products that retain their natural bioactive compounds. Processing technologies that preserve these compounds are likely to become increasingly important in the future. Further research may focus on developing optimized processing protocols that maximize nutrient retention while maintaining commercial feasibility. Such advancements can help strengthen the turmeric processing industry and improve product quality standards.



Conclusion

Turmeric owes much of its medicinal importance to curcumin and several other bioactive compounds that contribute to its nutritional and therapeutic value. However, conventional processing methods may lead to losses of these valuable constituents. Research has demonstrated that blanching turmeric rhizomes at $90^{\circ}\text{C} \pm 2^{\circ}\text{C}$ for five minutes is an effective pre-treatment for improving turmeric powder quality. The treatment helps retain curcumin, polyphenols, flavonoids, alkaloids, tannins, oleoresins, and essential oils while simultaneously enhancing colour, aroma, and overall acceptability. Adoption of such scientific processing techniques can contribute to the production of high-quality turmeric powder with greater nutritional, medicinal, and commercial value, ensuring that the full potential of this golden spice is preserved for consumers.





Soil health management for sustainable agriculture under changing climate in India

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Abstract

Human population in India is increasing and per capita availability of agricultural land is decreasing day by day. The biotic thrust on soil for food and fodder is increasing whereas the biotic and abiotic stress on soil under changing climate is increasing day by day. There is heavy depletion in Organic carbon, nitrogen, phosphorous, potassium, sulphur, boron and zinc from soils of India. In present scenario plant nutrient deficiency in agricultural soils coupled with increasing atmospheric temperature and erratic rainfall, draws the attention of one and all, to overcome the serious detrimental situation for sustainable food production in near future.

Presently, Organic carbon content is low in 53 %, medium in 28 % and high in 19 % of Indian soils which is a matter of great concern because more the organic carbon content of an agricultural soil, it is more healthy. Similarly the nitrogen content is low, medium and high in 73 %, 24 % and 3 % of Indian soils respectively which indicates low nitrogen fixation in these soils i.e. declined nitrogen fixing bacteria in these soils. Phosphorous content is low, medium and high in 16 %, 48 % and 36 % Indian soils which indicates 64 % soils are low to medium in phosphorous content. Only 36 % of soils are high in phosphorous content. This may be due to uncontrolled soil acidity or low population of phosphate releasing bacteria or both. Similarly potassium is low, medium and high in 12 %, 56 % and 32 % soils which indicates 68 % of soils are low to medium in potassium content and only 32 % soils are high in potassium content. So there is need for proper management practices for potassium in Indian soils.



Similarly the deficiency of Sulphur , Zinc and Boron are to the tune of 27 %, 37 % and 41 % of Indian Soils which draws serious attention of scientists , policy makers, teachers and students on the line as well as common farmers for proper management practices to overcome such problems .

(Source for Nutrient status ; soil health.dac.gov.in 2025-26)

Similarly deforestation and less recycling of organic matter to soil cause erratic rainfall , low water holding capacity of soil , runoff loss of water as well as loss of top soil making the agricultural land barren and unproductive .

Due to these problems today the health of agricultural soils in India is at risk which needs to be addressed with top priority for sustainable food , fodder and fiber production .

The burning problems associated with agricultural soils in India may be summarized as below :

1. Surface crusting and laterization :
2. Low Organic carbon content
3. Imbalanced nutrient application to soil
4. Soil acidity
5. Low nutrient use efficiency
6. Low earth worm and microbial population in soil
7. Loss of top soil
8. Decreasing water holding capacity of soil
9. Higher runoff of water

These Problems can be addressed technically as below

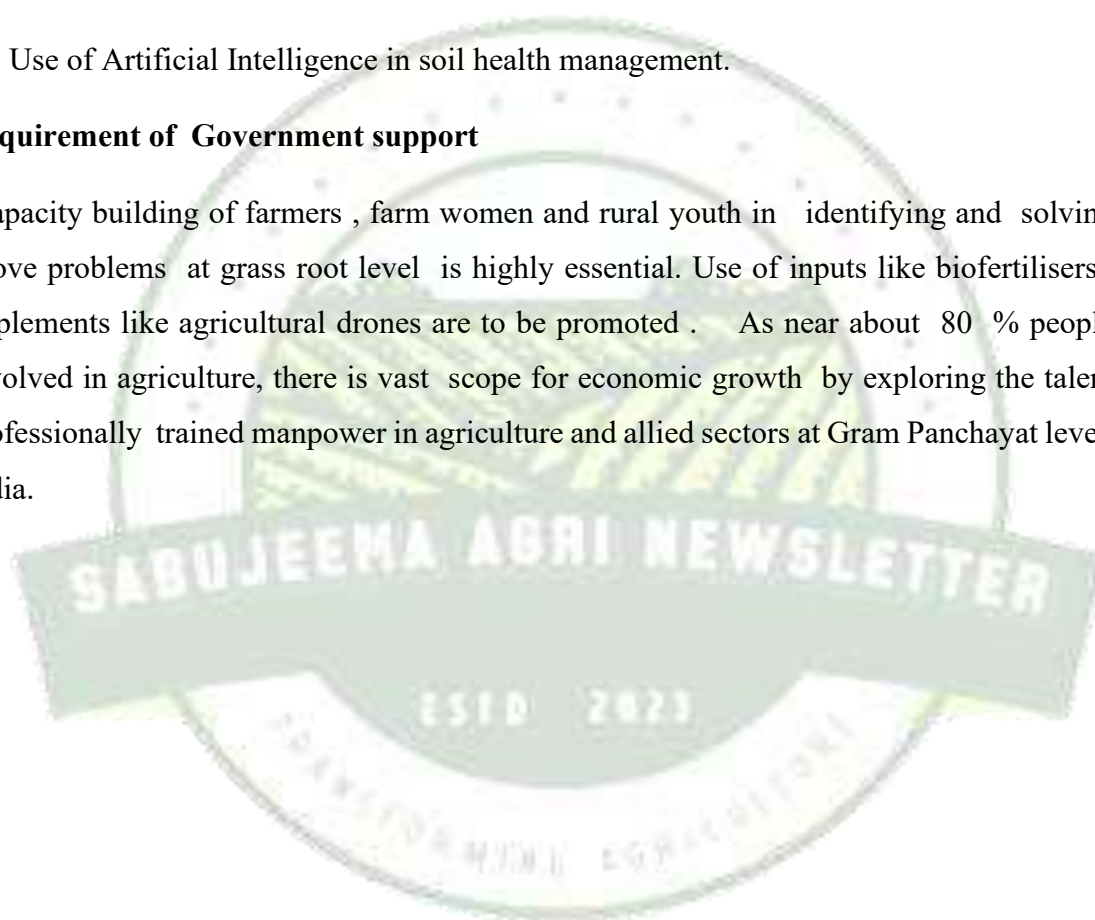
1. Recycling of Organic byproducts to soil by exploring vermitechnology i.e. vermiculture and vemicomposting .
2. Liming of acid soils
3. Inclusion of legumes in cropping pattern
4. Soil test based nutrient application with integrated nutrient management practices
5. Construction of low cost water harvesting structures , contour bonds, checkdams in rainfed areas in community approach.



6. Use of leaf colour chart for application of urea in rice and maize .
7. Exploring drone technology for real time monitoring of nutrient deficiency and water stress conditions.
8. Practising micro irrigation
9. Adoption of improved agronomic practices for enhancing water and nutrient use efficiency.
10. Practising agro forestry at suitable locations .
11. Practising Natural farming at suitable locations .
12. Use of Artificial Intelligence in soil health management.

Requirement of Government support

Capacity building of farmers , farm women and rural youth in identifying and solving the above problems at grass root level is highly essential. Use of inputs like biofertilisers and implements like agricultural drones are to be promoted . As near about 80 % people are involved in agriculture, there is vast scope for economic growth by exploring the talents of professionally trained manpower in agriculture and allied sectors at Gram Panchayat levels in India.





Sustainable Livestock Management through Vermicomposting

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Introduction

Livestock farming is an integral part of agriculture, providing food, income and employment to marginal and landless farmers. In India, the integration of crops and livestock and use of manure as fertilizer were traditionally the basis of farming systems. Despite this, the growth of the chemical fertiliser industry during the green revolution period made it possible to deliver inorganic plant nutrients at a low cost, which quickly replaced organic manures made from livestock dung. The adverse effects associated with modern agricultural techniques include the degradation of soil fertility due to the loss of nutrients and organic matter, erosion and salinity and environmental pollution. However, livestock excreta also generate large quantities of waste, especially cow dung, which often remains underutilized or improperly disposed of. This leads to environmental pollution, foul odour and the spread of diseases. Animal dung should not be wasted instead; it should be efficiently utilized through vermicomposting to conserve soil health and protect the environment. Vermicomposting offers a simple, eco-friendly and cost-effective method to convert livestock waste into valuable organic manure.

Vermicomposting has been arising as an innovative biotechnology for the conversion of agro-industrial wastes into value added products, which can be utilized for improving the soil structure and fertility in organic farming (Garg and Gupta, 2009). The potential benefits of vermicomposting of livestock excreta include control of pollution and production of a value-added product. Vermicomposting of different livestock excreta including cattle dung, horse waste, pig waste, goat waste, sheep waste, turkey waste and poultry dropping has been reported. Currently the fertilizer values of animal dung are not being fully utilized resulting in loss of potential nutrients returning to agricultural systems.



What is vermicomposting?

Vermicomposting is a mesophilic bio-oxidation and stabilisation process of organic materials that involve the joint action of earthworm and microorganism. This increases the rate of the decomposition process by accelerating the stabilisation of organic matter and greatly modifying its physical and biochemical properties. Microorganisms produce the enzymes that cause biochemical decomposition of organic matter, but earthworms are the crucial drivers as they stimulate and increase biological activity by fragmentation and ingestion of organic matter and this will increase the surface area to be exposed to microorganism. Earthworms act as mechanical blenders and by comminuting the organic matter they modify its physical and chemical status by gradually reducing the C: N ratio and increasing the surface area exposed to microorganism. They also serve as agent of turning and aeration. Composting and vermicomposting are considered as the best option for biomass management.

Utilization of Cow Dung through Vermicomposting

Cow dung is one of the most readily available organic wastes in rural areas. When left unused, it contributes to methane emissions and environmental degradation. Vermicomposting provides an effective way to recycle this waste. In this process, cow dung is first partially decomposed and then fed to earthworms such as *Eisenia foetida*. It is widely used for vermicomposting of cow dung in Northern India. These earthworms break down the organic material and convert it into nutrient-rich compost known as vermicast. This process not only reduces waste but also produces high-quality organic fertilizer, which can be use as sustainable product. Vermicompost has also been reported to contain biologically active substances such as plant growth regulators. Moreover, the worms themselves provide a protein source for animal feeds.

Vermicomposting Process

Vermiculture is the term used to signify the growth of earthworms in organic waste, while vermicomposting is the term used to describe the processing of organic waste by earthworms. Vermicomposting comprises a number of simple steps, including: **1. First stage of pre-composting:** Before being fed to earthworms, the organic waste is precomposed for roughly 15 days. This stage involves the breakdown of easily decomposable chemicals and the removal of potentially volatile substances that could be harmful to earthworms **2. Mesophilic phase:** In this stage, organic waste materials are prepared for the production of organic manures by earthworms using their special ability to break up organic matter, integrate it with soil particles



and boost microbial activity. **3. The stabilisation and maturation stage:** Vermicompost is a substance that resembles peat and contains most of the nutrients that plants can need, including calcium, potassium, magnesium, phosphates and nitrates. It offers plenty of places for microbial activity and nutrient retention due to its high porosity, water-holding capacity and surface area. Vermicompost's have been shown to include plant growth regulators and other compounds that affect plant growth, such as auxins, cytokinin's, humic chemicals, etc., created by bacteria. The majority of plant-available nutrients, including nitrates, phosphates, exchangeable calcium and soluble potassium, are found in vermicompost. It supports better nutrient absorption and root growth. It enhances the macro and micronutrient status of the soil. It has the ability to recycle trash into useful fertiliser. Vermicompost made from cow dung is therefore essential for preserving soil fertility over the long run.

Vermicomposting as an effective tool in manure management

Sustainable livestock management focuses on efficient resource use and environmental protection. Vermicomposting can help to achieve this by converting livestock waste into valuable manure, improving farm hygiene and reducing odours, supporting integrated crop-livestock systems, enhancing overall farm productivity. By recycling cow dung into vermicompost, it can be utilised as an organic manure and make livestock farming becomes more sustainable, economical and environmentally friendly.

Vermicomposting is a low-cost technique that can offers multiple economic advantages as-1. Reduces expenditure on chemical fertilizers 2. Provides an additional source of income through sale of compost 3. Requires minimal investment and maintenance. Thus, it helps farmers convert waste into wealth while improving their livelihood.

Environmental Protection and Sustainability

Vermicomposting contributes significantly to environmental conservation. It helps to reduce accumulation of livestock waste, minimizes greenhouse gas emissions, prevents soil and water pollution. It promotes recycling of organic nutrients. By converting waste into a useful resource, vermicomposting supports an effective technique and sustainable management system. It aligns with the principles of eco-friendly farming and reduces dependency on chemical fertilizers.



Challenges and Limitations

Despite its benefits, vermicomposting requires proper knowledge and management. Some challenges include- maintaining suitable temperature and moisture, protecting earthworms from predators, initial setup and training requirements. However, these challenges can be easily overcome with awareness and proper guidance.

Conclusion

Vermicomposting is an effective and sustainable solution for managing livestock waste as well as promoting sustainable farming system. Utilizing cow dung through vermicomposting not only prevents waste but also conserves soil health, protects the environment and promotes sustainable agriculture. By adopting this eco-friendly practice, farmers can ensure cleaner farms, healthier livestock and improved productivity. Vermicomposting truly represents a step towards a greener and more sustainable future in livestock management.

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Tips to improve soil health naturally

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Introduction

Soil, the topmost layer of the earth's crust, is formed through various physical, biological and chemical processes. Soil health, a living system within ecosystem and land use limits, supporting plant and animal production, maintaining, or enhancing water and air quality, and promoting plant and animal health. Good soil health is essential not only for high-value crop production but also for sustaining ecosystem services. More than 99% of our food comes from the soil. However, soil health degradation worldwide has reduced soil fertility, agricultural productivity, water availability, and the health of forest and pasture ecosystems. This decline has also impacted human nutrition, with around 66% of the global population being malnourished. Therefore, soil health is vital for the wellbeing of humans, wildlife, and flora and fauna of various ecosystems.

Soil harbours about 25% of the world's biodiversity, with a teaspoon of healthy soil containing approximately one billion microorganisms. This biodiversity is the foundation of life on earth. Besides agriculture, topsoil is valuable for construction materials, grasslands, and forests. Biological components of soil, such as microbial community diversity, abundance, activity, and stability, are key indicators of soil quality. Soil biota plays a crucial role in mineralizing plant residues into easily available nutrients, accelerating decomposition through enzyme production, and transforming nitrogen between organic and inorganic forms. These microbial communities are crucial for the stability and productivity of agroecosystems.

Soil Health in India

Agriculture in India faces significant challenges due to poor soil health. Most of Indian soils have low nutrient levels, with an average soil organic carbon (SOC) of around 0.54%. Land degradation affects about 30% of the country's geographical area, leading to nutrient deficiencies that impact local nutrition. Nutrient depletion and fertilizer use in improper ratio reduce productivity. Sustainable practices like replenishing soil nutrients, application of fertilizers based on soil analysis, and increasing organic content are essential for food



production. Additionally, approximately 3 billion tonnes of soil are eroded annually by water and wind in India.

Importance of Soil Health

Soil is a living ecosystem made up of minerals, organic matter, air, water, fungi, bacteria, worms, and countless other organisms. When soil is healthy, it holds nutrients well, drains properly, and gives roots the support they need to grow strong.

Improving soil health naturally can lead to:

- Better plant growth and higher yields
- Improved water retention capacity and drainage systems
- Reduced erosion and compaction of soil crust
- Increased nutrient availability to plants
- More beneficial microbial activity to increase sustainable soil fertility status

Requirement of a Soil Test

Before making changes, it helps to understand what the soil needs. A simple soil test can reveal pH levels, nutrient deficiencies/ toxicities, and organic matter content. This gives a clear starting point and prevents unnecessary soil amendments.

If the soil is too acidic or too alkaline, plants may struggle to absorb nutrients even when those nutrients are present. Knowing the soil's condition makes it easier to choose the most effective natural improvements.

Addition of Organic Matter Regularly

One of the best ways to improve soil health naturally is to add organic matter. Compost, well-rotted manure, leaf mould, and shredded plant material all feed the soil and improve its structure.

Organic matter helps soil to:

- Hold moisture during dry periods
- Release nutrients slowly over time
- Support earthworms and microbes



- Loosen heavy clay and improve sandy soil

Spread a layer of compost, manures or leaf moulds over garden beds at least once or twice a year can dramatically improve soil fertility and plant health.

Use of Compost as a Soil Builder

Compost is sometimes called 'Black Gold' for a reason. It is one of the most powerful natural amendments for improving soil health. Instead of throwing away kitchen scraps, grass clippings, and fallen leaves, they can be turned into compost and returned them to the soil. Healthy compost provides a steady supply of nutrients and beneficial microorganisms. It also helps reduce waste and supports a more sustainable gardening system. It is advised to apply compost as a top dressing rather than digging it deeply into the soil. This protects soil structure and allows soil life to do the work naturally.

Use of Mulch to Protect and Feed the Soil

Mulching is a simple, effective way to improve soil naturally. A layer of organic mulch such as straw, wood chips, shredded leaves, or grass clippings helps protect the soil surface from heat, rain, and erosion and conserve the moisture.

Mulch also breaks down over time and aid to adding organic matter to the soil. It suppresses weeds, keeps moisture in the ground, and creates a more stable environment for roots and soil organisms. For best results, application of 5 to 10cm of mulch around plants, keeping it slightly away from stems and trunks to prevent rot.

Practice of Crop Rotation

Growing the same crop in the same land year after year can drain specific nutrients from the soil and increase insect-pests and disease pressure. Crop rotation helps prevent these problems by changing what is planted in each area from season to season.

For example, follow heavy-feeding crops like brinjal, potato, or maize with legumes, leafy greens, or root crops. Selection and use of crops from different plant families return different nutrients, which helps maintain a better soil balance over a period of time. Crop rotation improves soil's physical texture by rotating different plants whose roots reach various soil depths instead of leaving the soil in its compressed state. Crop rotation with cereal rye, oats, and certain strains of wheat protect topsoil and almost acts as a blanket for crops. Crop rotation improves water use efficiency by increasing the amount of organic matter in the soil, which



can improve soil structure and water-holding capacity. Also, this method helps to preserve moisture in deep soil layers, which plants can use during droughts. This way, farmers can reduce irrigation water usage. Research indicates that up to 60 percent of eroded soil is carried into streams, lakes, and rivers, contributing to water pollution. By integrating crop rotation methods, farmers can not only reduce soil erosion but also promote healthier, more sustainable farmland.

Grow of Cover Crops

Cover crops are one of the most effective natural tools for improving soil health. These plants are grown specifically to protect and enrich the soil between main planting seasons.

Popular cover crops include clover, rye, vetch, buckwheat, and legumes which can:

- Prevent soil erosion
- Suppress weeds growth
- Add organic matter
- Fix atmospheric nitrogen into the soil
- Improve soil structure

Once the cover crop matures, it should be cut down and left on the surface as mulch or lightly incorporated into the top layer of soil.

To Encourage Beneficial Soil Life

Soil health depends heavily on living organisms. Earthworms, fungi, bacteria, and insects present in the soil all play important roles in breaking down organic material and making nutrients available to plants.

To support beneficial soil life:

- Soil should be covered with mulches or plants
- The soil should be fed with compost and organic matter
- Synthetic chemicals should be avoided when possible
- The soil disturbances should be minimized



Judicious use of Water

Water management plays a vital role in soil health. Too much water can lead to compaction, nutrient leaching, and root problems, while too little water can slow microbial activity and nutrient availability for plant growth.

Watering deeply and less frequently lead to encourage roots to grow downward. Early morning watering is often ideal because it reduces evaporation and allows foliage to dry during the day. Using drip irrigation or soaker hoses can also improve efficiency and reduce soil disturbance.

Reduction in Chemical Dependence

Frequent use of chemical fertilizers and pesticides can disrupt the balance of soil life. While they may provide short-term results, they often do not support long-term soil fertility.

Natural soil improvement focuses on building resilience rather than forcing rapid growth. By relying on compost, mulch, cover crops, and balanced organic amendments, you create a healthier foundation that gets better over time.

To make Balance Soil pH Naturally

Soil pH determines how well plants absorb nutrients. If the soil is too acidic or too alkaline, the plants show poor growth even when nutrients are present.

Natural ways to adjust soil pH include:

- Addition of compost to buffer pH over time
- Use of lime to raise pH in acidic soils
- Use of elemental sulphur to lower pH in alkaline soils
- Choosing plants suited to native soil conditions

Always pH adjustments should be done based on soil test results for the best outcome.

Feed the Soil, Not Just the Plants

A common mistake is found in gardening is focusing only on plant nutrition. Healthy soil creates healthy plants. When someone feed the soil with organic matter, it can support the full ecosystem that delivers nutrients naturally.



A soil improvement program should be thought as a long-term investment. The more one build soil structure, protect soil life, and reduce stress on the ground, the more productive and resilient the garden becomes.

Simple Habits That Make a Big Difference

1. Test the soil every few years
2. Balanced crop nutrition, incorporating the 4Rs (Right source, Right rate, Right time, Right place), ensures maximum yield and improved plant health.
3. Add compost regularly
4. Use Biofertilizers to increase nutrient availability, enhance soil fertility, protect plants from pathogens, and improve soil health with minimal environmental impact
5. Use organic mulch year-round
6. Rotate crops and grow cover crops
7. Minimize tilling and compaction
8. Water wisely and avoid runoff

Farming practices for improvement of soil health naturally

Organic Farming: The practice of organic farming as the most sustainable agricultural system is rapidly growing worldwide because it not only improves the physical, biological, and environmental resources such as soil nutrient mineralization, microbial activity, abundance and diversity, and groundwater quality but also yield and product quality as evidenced in wheat, potato, watermelon, and strawberry (Gong et al., 2011; Schrama et al., 2018). Leguminous crops (e.g., *Sesbania* spp. and alfalfa) that are used widely in organic farming have been known to increase soil organic matter, N supply capacity and soil N sequestration by about 50%. A long-term (12 year) study with rice (*Oryza sativa*) and corn (*Zea mays*) crops showed that organic systems using compost and peat sources had higher microbial population and enzyme activities compared to conventional systems (Chang et al., 2014). The diversity and dominant soil bacterial population (β -proteobacteria, acidobacteria, and α -proteobacteria) in organic and conventional banana (*Musa acuminata*) plantations was significantly higher in organic systems. Growing vegetable crops such as tomato (*Solanum lycopersicum*), French bean (*Phaseolus vulgaris*) and lettuce (*Lactuca sativa*)] under organic and conventional culture for



three years revealed that organic farming using compost increased soil CO₂ respiration (soil health indicator) and enzyme activities (fluorescein diacetate hydrolysis, phosphatase, and arylsulphatase activities) compared to conventional mineral fertilizer (NPK). Also, organic culture proved to suppress soil pathogens, such as Fusarium wilt in cucumber (*Cucumis sativus*) and plant parasitic nematodes *Pratylenchus* and *Meloidogyne* in maize and bean compared to conventional culture systems.

Organic farming can improve soil physical and chemical properties. Organic systems in a clay soil increased soil water content (~15%) and retention capacity (10%) and reduced soil bulk density (8%) in the top 20 cm soil layer as compared to conventional systems. In addition, organic farming is a good source of macro-nutrients.

The main challenge in organic farming is to synchronize nutrient release, specifically N, with seasonal growth demand of crops. Organic materials do not release adequate amount of N to succeeding crops beyond 6 to 8 weeks after incorporation. Low N supply during the crop growth stages leads to a reduction in leaf chlorophyll content, inefficient water uses and subsequently lower growth and yield. Organic soil amendments (organic vs conventional fertilizers) increased marketable yield, ascorbic acid and phenolic compounds in collard (*Brassica oleracea*) and kale (*Brassica oleracea*). Meta-data studies of conventional and organic growing systems showed that organic products (fruits, vegetables, and grains) had lower NO₃⁻ content and pesticide residue levels and higher nutrient (Fe³⁺, Mg²⁺, P) and vitamin C.

Crop rotation with legumes usually provides the most N for organic farming systems. Several plant-based (e.g., leguminous crop and maize meals) and animal-based (e.g., blood and fish meals, bones, and composted-manure) fertilizers are available commercially for organic growers. Plant-based fertilizers such as leguminous crops have been used widely as green manures to increase the available N in the soil. Legumes can fix atmospheric N in the soil, reduce the risk of NO₃⁻ leaching, improve soil physical and chemical properties as well as fruit quality. Long-term, plant-based fertilizers (leguminous crop and maize meals) can be an ideal choice for improving soil health, while animal-based (blood and fish meals, bones and composted-manure) may be a superior option for organic growers when yield and cost are the main concerns, especially short-term.

Tillage Practices: Excessive tillage increases soil oxygen, stimulating biological activity and decomposing organic matter. It disturbs soil aggregates, exposing organic particles to



microbes. This reduces soil health over time and increases erosion risk. Tillage practices affect soil chemical and physical properties, as well as fruit quality and crop yield. Adopting useful tillage practice is a prerequisite to sustain soil health and crop production. Conservation tillage practices can increase soil microbial activities, soil moisture, organic matter, aggregate stability, cation exchange capacity and crop yield. Tillage intensity significantly reduced soil macro- and micro-aggregate stability. Conservation tillage practices increased soil available P in the topsoil (0–20 cm) by 3.8%, K by 13.6% and soil organic matter by 0.17% compared to conventional. Maintaining crop residues on the topsoil surface layer can also reduce soil erosion and increases soil moisture content.

Conservation tillage increases bacterial and fungi abundance and nematode, earthworm, and gram-positive bacteria than conventional system. No-tillage can also lead to higher soil bulk density and compaction (higher penetrometer resistance) in the topsoil layer. Conversely, conventional tillage practices aerate soil surface and reduces compaction, reduces weeds pressure, and incorporates crop residues and fertilizers.

Conclusion

Soil health and soil life are closely linked to agricultural methods and management systems. Improving soil health and life is essential for soil productivity, beneficial soil biota, soil protection, and stabilization. However, excessive use of chemicals and conventional farming practices negatively impact soil health. Intensive farming further depletes soil, threatening future food production.

To sustainably increase soil fertility, stabilization, health, and biodiversity, we must enhance the soil's physical, chemical, and biological properties using composting, mulching and crop rotation. This approach will also improve global food security. While conventional farming boosts food production, incorporating organic inputs, compost, and fertility restoration practices is crucial for better quality food and higher yields. Sustainable soil management practices offer long-term benefits for soil health, ecosystem functioning, greenhouse gas emission control, and climate change mitigation.

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Managing Weed Competition in High-Value Horticultural Crops

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Introduction

Horticulture plays an important role in Indian economy. The diversity in soil and climatic conditions prevailing in India provide ample opportunities for growing large variety of fruits, vegetables and other horticultural crops in different regions of India. Fruits, vegetable and flower crops are major components of the horticultural industry in India. Weed management is an important aspect in the successful production of these crops because it reduce crop yields, lower their quality and increase costs of production. They host pests and diseases thereby raising the need to control them as well. It may involve different integrated weed management practices such as chemical, mechanical, cultural and or non chemical methods. The decision of method to be used depends on the environmental conditions, available labour, weed population, the crop, desired management practices and the cost of controlling weeds. The major aim is to manage the weed population to a level below that will cause a reduction in economic return for the farmer.

Wide range of weed species affects the productivity of horticultural crops through competition for light, water and mineral nutrient. Apart from this, they act as alternate host for many pests and pathogens which cause heavy yield losses. The weeds besides competing with the trees interfere with the plant protection measures, harvesting, pruning and other cultural operations. Weed control is especially important early in the season when weed competition can substantially reduce vigour, uniformity and overall yield. The period from emergence to four weeks has been found to be critical in the competition of weeds in many row crops including vegetables.

Critical period of weed control

This period has been defined as an interval in the life-cycle of the crop when it must be kept weed free to prevent yield loss. Horticultural crops are very sensitive to weed competition and



need to keep them weed-free, from planting, emergence or until the end of their critical weed free period. If the crop is kept weed-free for the critical period, generally no yield reduction would be there. Again, weeds emerging after the critical weed-free period will not affect yield, but control efforts after this time may make harvest more efficient, or reduce weed seed banks and reduce weed problems in subsequent years. The critical period of weed competition is usually longer in direct-seeded than in transplanted crops.

Thus, effective weed control is imperative for the profitable production of horticultural crops.

Commonly infested annual and perennial weeds of horticultural crops in India

1	Annual weed	
	Summer season	Winter season
2	Setaria verticillata Dactyloctenium aegyptium Eleusine indica Digitaria sanguinalis Echinochloa colona Trianthema portulacastrum Cucumis callosus Amaranthus viridis Digera arvensis Euphorbia microphylla Phyllanthus niruri Portulaca oleracea Commelina benghalensis Cannabis sativa Setaria verticillata	Phalaris minor Avena ludoviciana Lolium temulentum Polypogon monspeliensis Poa annua Sonchus arvensis Rumex dentatus Euphorbia simplex Chenopodium album Melilotus alba Stellaria media Coronopus didymus Malva parviflora
	Perennial weed	
	Cynodon dactylon Cyperus rotundus Parthenium hysterophorus	Convolvulus arvensis Cuscuta reflexa Cuscuta chinensis Orobanche aegyptiaca Cirsium arvense

Weed management involves a combination of different control methods to effectively reduce weed growth while minimizing harm to the environment. The choice of method depends on various factors.

The methods used for the effective weed control are as follows:

1. Direct methods a. Cultural methods b. Mechanical control c. Chemical control d. Biological control



2. Indirect methods a. Land preparation b. Selection varieties c. Plant density d. Fertilizer application.

Tillage: Tillage is done in row crops by cultivators after planting to control weed growth. This method is more effective and economical.

Hoeing: It is highly effective means of weed control.

Hand weeding: It is easy but laborious and time consuming work

Mulching: Organic and inorganic mulching reduces the growth of weeds. Mulching materials, such as hay, grass clippings, straw, sawdust, rice hull and different colours plastic film are applied, which exclude light thereby preventing photosynthesis and growth of weeds.

Intercropping: Raising of cover crops, intercrops and green manure crops are helpful in checking the weeds. But, intercropping or cover cropping in the orchards is not desirable during blooming and fruiting periods, during that time the fruit trees require maximum moisture and nutrients. Eg. Cowpea, green gram, black gram, dhaincha, boru etc.

Planting to moisture: This is generally used in vegetable crops. The majority of small seeded weeds germinate in upper 1 to 2 inches of soil. This aspect of the germination ecology of weeds can be exploited for control of these weeds. After the weeds are killed by cultivation, the top 1 to 2 inches of soil are allowed to dry and form a 'dust mulch'. At planting, the dust mulch is pushed away and large seeded vegetables such as corn or beans can be planted into the zone of soil moisture. These seeds can germinate, grow and provide partial shading of the soil surface without supplemental irrigations that would otherwise provide for an early flush of weeds.

Crop rotation: Crop rotation is a key control method to reduce weed problems in vegetables. It was considered for a long time to be a basic practice for obtaining healthy crops and good yields. This concept was mistakenly eliminated with the use of more agrochemicals. At present, however, crop rotation is gaining interest and is of value in the context of integrated crop management.

Planting time: The crop planted at the right time showed more competitiveness towards weeds than late planted crop. Crops may be divided into warm and cool-season plants, depending on the optimal temperature for their growth. The planting date effects the time of emergence and early seedling vigour of the crop, which are important in determining crop competitiveness.



Solarisation: In this process, moist soil is covered with a clear, thin transparent plastic sheet, to trap the soil radiation for 30-45 days. Solarization works when the heat created under the plastic film becomes intense enough to kill weed seeds. The maximal soil temperature reaches nearly 60°C under polyethylene covered plots. The factors involved in solarization are soil temperature, moisture and probably gases due to which solarization reduces the germination, establishment and biomass of heat sensitive weed species.

Mechanical method: Mechanical removal of weeds is both time consuming and labor-intensive but is one of the most effective methods. Mechanical weed management starts with seedbed preparation. Moldboard plowing is usually the first step in mechanically managing weeds. It is particularly useful in controlling emerged annual weeds. Rotary hoeing needs to be done after the weeds germinate but before they emerge; it controls only small-seeded weeds.

. When perennial weeds are present, adequate tools will depend on the types of rooting. Pivot roots (*Rumex* spp.) or bourgeon roots (*Cirsium* spp.) require fragmentation and this can be achieved by using a cultivator. Fragile rhizomes (*Sorghum halepense*) require dragging and exposure at the soil surface for their depletion, but flexible rhizomes (*Cynodon dactylon*) require dragging and removal from the field. This can be done with a cultivator or harrow. Tubers (*Cyperus rotundus*) or bulbs (*Oxalis* spp.) require cutting when rhizomes are present and need to be dug up for exposure to adverse conditions (frost or drought). This can be done with the mouldboard or disk ploughing. Chisel ploughing is useful for draining wet fields and reducing the infestation of deep-rooted hygrophilous perennials (*Phragmites*, *Equisetum*, *Juncus*).

Biological Control: Myco-herbicides are a preparation containing pathogenic spores applied as a spray with standard herbicide application equipment. Eg: a weevil for the aquatic weed salvinia, rust for skeleton weed, and a caterpillar (*Cactoblastis* sp.) to control prickly pear. Specific insects are used to feed exclusively on particular weed species, exhausting their energy reserves, stunting root growth, and reducing their competitive ability. The moth borer *Bactra verutana* specifically targets nutsedge (*Cyperus rotundus*), while the beetle *Altica cynanea* defoliates *Ludwigia*.

Chemical control: In this method the herbicides are applied as pre and post emergence systemic, contact for controlling weeds such as Pendimethalin, Metribuzin, DCPA, Clomazon, Propachlor, Linuron, Oxiflufen, Rimsulfuron, Ioxinil, Diuron or Simazine, Glyphosate and



Paraquat in horticultural crops. This method of control is highly effective and economical as the other methods demand more labour and cost.

Good practices during the use of herbicides:

- Periodically inspect the fields and assess the weed of importance. Identify correctly the major weeds.
- The weed and crop stage of growth must be taken into account.
- Careful selection of the product and dosage, bearing in mind points one and two.
- Read the product label and follow the recommendations.
- Avoid adverse conditions at the time of application: wind, temperatures, rainfall. Do not delay treatment.
- Quality of the spraying is obtained by the correct calculation of dosage (surface to be treated must be well measured) and by the spraying equipment, which must be calibrated and in good condition (especially nozzles).
- Band or patch application to save herbicide and reduce residues.
- Keep to the environmental norms: avoid spills, drift, respect the edges, water ways, and sensitive areas. Rinse all empty cans or containers thrice and do not re-use them.
- To avoid propagation of resistant species, the same herbicide or herbicides with the same mode of action must not be used repeatedly.

Integrated weed management: It is basically an integration of effective, dependable and workable weed management practices that can be used economically as a part of sound farm management system. Such an approach is the most attractive alternative from agronomic, economic and ecological point of view. It is the application of numerous alternative technologies to reduce the weed population, abundance, including cultural, genetic, mechanical, biological and chemical control.

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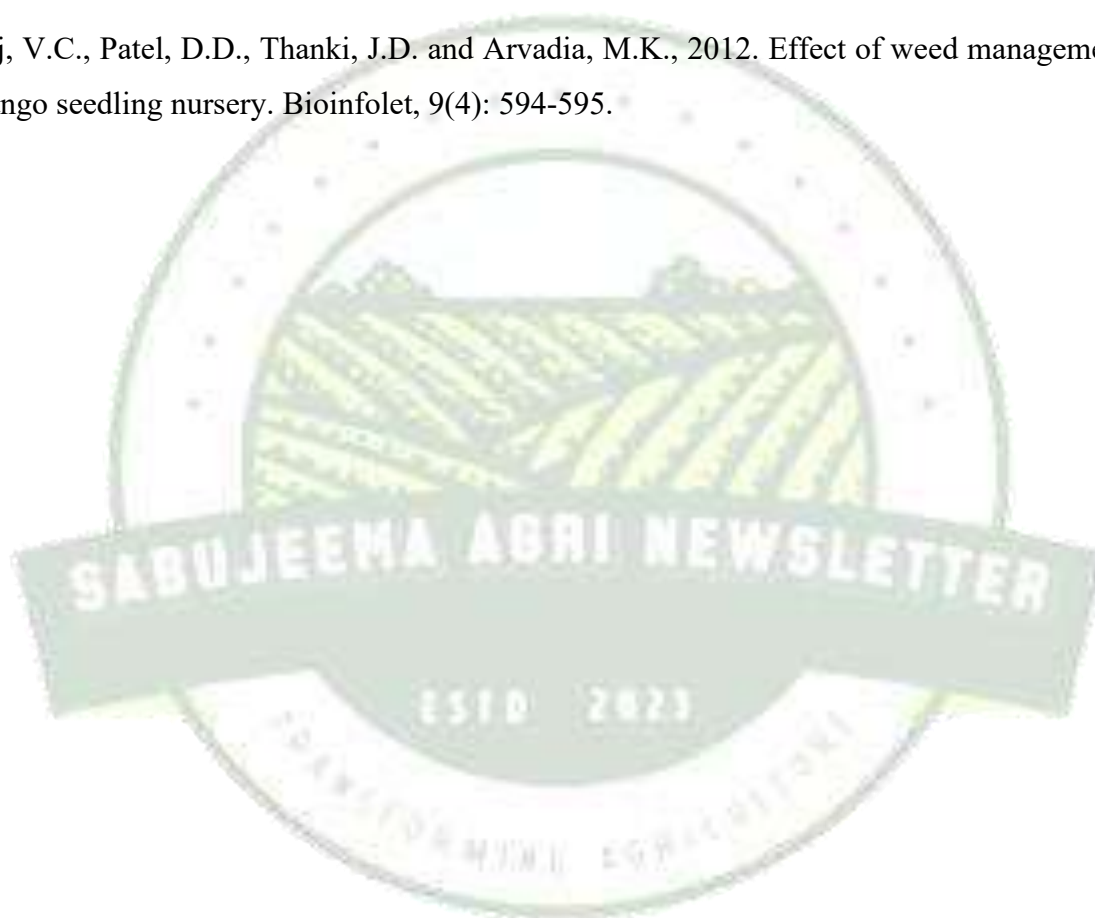


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Importance of Yellow Sigatoka in banana and its management

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Symptoms

Yellow Sigatoka, also known as Sigatoka leaf spot, is one of the most widespread foliar diseases of banana and plantain worldwide. The disease is caused by the fungal pathogen *Pseudocercospora musae* (formerly *Mycosphaerella musicola*). Although generally less destructive than Black Sigatoka (*Pseudocercospora fijiensis*), Yellow Sigatoka remains a major constraint to banana production, particularly in regions characterized by high humidity, moderate temperatures, and frequent rainfall. The disease reduces photosynthetic efficiency, impairs plant growth, decreases fruit yield, and adversely affects fruit quality, thereby causing significant economic losses. Yellow Sigatoka primarily affects banana leaves, where it interferes with photosynthesis by destroying leaf tissue. Healthy banana plants rely heavily on functional leaf area to support fruit filling and bunch development. Therefore, any reduction in leaf area due to disease can directly influence productivity. Severe infections may lead to premature leaf senescence, reduced bunch weight, smaller fruit size, delayed maturity, and lower market value. In commercial plantations, yield losses ranging from 20 to 50% have been reported under conditions favorable for disease development.

The pathogen survives on infected leaf debris and spreads mainly through airborne spores and rain splash. Infection begins when fungal spores land on susceptible leaf surfaces and germinate under moist conditions. The fungus penetrates through stomata and colonizes leaf tissues. Initial symptoms appear as small pale-yellow streaks parallel to leaf veins, which gradually enlarge into elongated spindle-shaped lesions. As the disease progresses, lesions turn brown with grey centres and eventually coalesce, causing extensive necrosis and leaf death. Under severe infection, large portions of the leaf become non-functional, drastically reducing photosynthetic capacity.



Fig. 1. Illustration of Symptoms of Yellow Sigatoka in banana

Epidemiology and Disease Cycle

The disease cycle of Yellow Sigatoka begins with the production of conidia and ascospores on infected leaf tissues. These spores are dispersed by wind, water splash, irrigation droplets, and agricultural operations. Upon reaching healthy leaves, spores germinate in the presence of moisture and penetrate through stomatal openings. Following penetration, the fungus grows intercellularly within leaf tissues, extracting nutrients from host cells. The incubation period may vary from two to six weeks depending on environmental conditions and cultivar susceptibility. New spores produced on infected lesions initiate secondary infection cycles, allowing rapid disease spread during favorable weather conditions. The continuous production of spores throughout the growing season makes Yellow Sigatoka a polycyclic disease. Therefore, effective management requires an integrated and continuous approach rather than reliance on single control measures.

Impact on Banana Physiology and Yield

Yellow Sigatoka significantly affects several physiological processes in banana plants. Destruction of chlorophyll-containing tissues reduces photosynthetic efficiency and carbohydrate production. Consequently, fewer assimilates are available for fruit growth and development. The disease also accelerates leaf senescence, shortening the functional lifespan of leaves. Since banana fruits depend heavily on photosynthates produced by leaves during bunch filling, premature leaf loss results in reduced bunch weight and poor fruit quality. In



severe cases, infected plants may retain fewer than five functional leaves at flowering, which is insufficient for optimal bunch development. Furthermore, disease-induced stress weakens plants and increases susceptibility to other pathogens and environmental stresses. Reduced vigor may impair nutrient uptake, delay maturity, and lower plantation productivity over multiple cropping cycles.

Integrated and Scheduled Management of Yellow Sigatoka

Effective management of Yellow Sigatoka requires an integrated disease management (IDM) approach combining cultural, biological, nutritional, and chemical measures. Since the disease develops continuously throughout the growing season, management practices must be implemented systematically according to crop growth stages and environmental conditions.

Cultural Management

Cultural practices form the foundation of Yellow Sigatoka management. Proper plantation sanitation significantly reduces inoculum levels and slows disease spread. Regular removal of infected leaves decreases spore production and limits secondary infections. Diseased leaf portions should be pruned carefully and destroyed away from the plantation. Adequate plant spacing improves air circulation and reduces humidity within the canopy. Improved ventilation accelerates leaf drying following rainfall or irrigation, thereby reducing opportunities for fungal infection. Similarly, maintaining proper drainage prevents excessive moisture accumulation and minimizes disease development. Removal of excess suckers is another important practice. Overcrowded plants create dense canopies that favor pathogen survival and spread. Maintaining an appropriate number of healthy suckers ensures better aeration and sunlight penetration. Balanced nutrition also plays a critical role in disease management. Adequate potassium and silicon nutrition enhances leaf strength and improves resistance to fungal infection. Excessive nitrogen fertilization should be avoided because it promotes lush succulent growth that is more susceptible to disease.

Nutritional Management

Nutrient management is closely linked to disease resistance. Balanced fertilization strengthens plant vigor and enhances the ability of banana plants to tolerate disease pressure. Potassium plays a particularly important role in reducing Sigatoka severity. Adequate potassium nutrition improves cell wall strength, enhances stomatal regulation, and supports defense-related metabolic processes. Calcium and silicon also contribute to structural integrity and disease



resistance. Application of organic manures, compost, vermicompost, and biofertilizers improves soil microbial diversity and supports disease-suppressive microbial communities. Enhanced soil health indirectly contributes to reduced disease incidence.

Chemical Management

Although biological and cultural methods are essential, fungicides remain important components of integrated management programs in commercial plantations, particularly under high disease pressure. However, fungicides should be used judiciously to prevent resistance development and minimize environmental impacts. Protectant fungicides such as mancozeb and chlorothalonil provide preventive protection by inhibiting spore germination on leaf surfaces. Systemic fungicides belonging to triazole, strobilurin, and benzimidazole groups offer curative activity against established infections.

To avoid fungicide resistance, rotation among fungicides with different modes of action is strongly recommended. Fungicide applications should be based on disease monitoring and environmental conditions rather than fixed calendar schedules whenever possible.

Biological Management

Beneficial microorganisms have gained increasing attention as environmentally sustainable tools for Sigatoka management. Several bacterial and fungal biocontrol agents suppress pathogen development through competition, antibiosis, and induced resistance. Species of *Bacillus subtilis*, *Bacillus amyloliquefaciens*, *Pseudomonas fluorescens* and *Trichoderma harzianum* have demonstrated effectiveness against Sigatoka pathogens. These microorganisms colonize leaf surfaces and produce antifungal compounds that inhibit spore germination and pathogen growth. Foliar applications of *Pseudomonas fluorescens* can reduce lesion development while simultaneously inducing systemic resistance within banana plants. Similarly, *Trichoderma* species produce enzymes and secondary metabolites that suppress fungal pathogens and enhance plant defense responses. The integration of microbial inoculants with organic amendments often enhances their efficacy by promoting establishment and persistence of beneficial microbial populations.

Climate change is expected to alter the epidemiology of Sigatoka diseases through changes in rainfall patterns, humidity, and temperature. Consequently, climate-smart management strategies are becoming increasingly important. These include the use of disease-resistant cultivars, microbial biocontrol agents, precision disease forecasting systems, improved canopy



management, and enhanced soil health practices. The integration of beneficial microbial consortia with climate-resilient production practices offers considerable potential for reducing dependence on fungicides while maintaining effective disease control. Future research focusing on banana phyllosphere microbiomes, synthetic microbial communities, and nano-formulated biocontrol agents may further improve sustainable management of Yellow Sigatoka under changing climatic conditions.

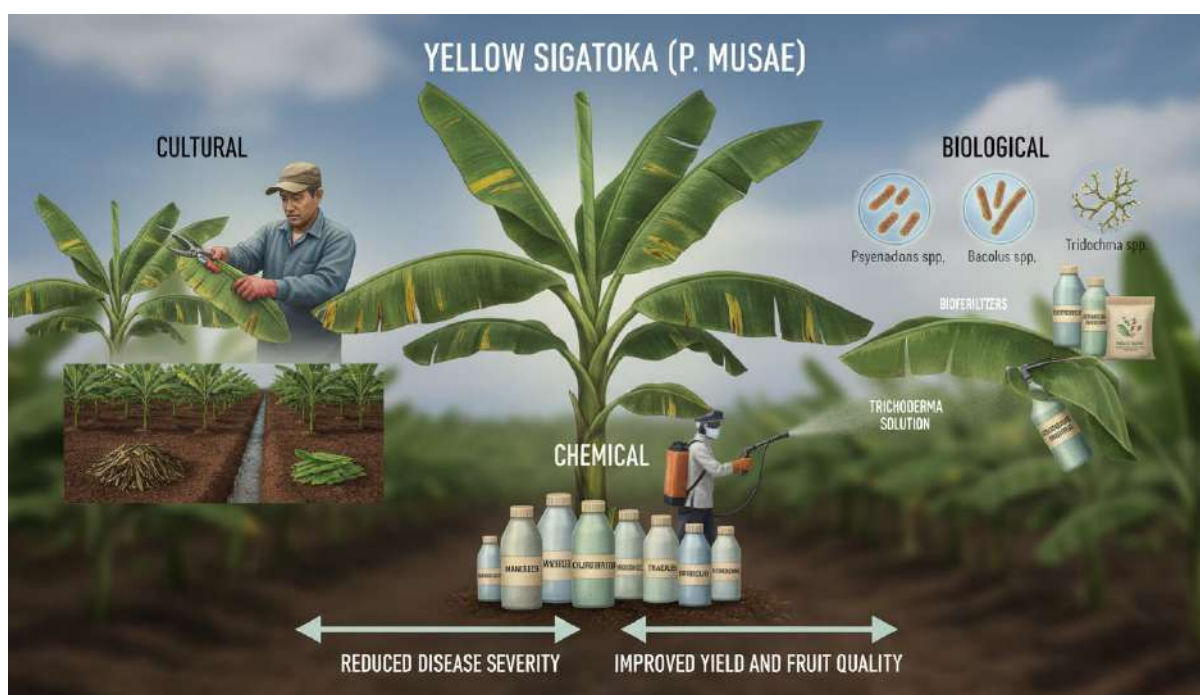


Fig. 2. Illustration of Integrated management of Yellow Sigatoka in banana

Table 1. Recommended Integrated Management Schedule for Yellow Sigatoka in Banana

Crop Stage	Management Practice	Purpose
Planting	Use disease-free tissue-cultured plants; apply biofertilizers and <i>Trichoderma</i> in pits	Reduce initial inoculum and establish beneficial microbes
1–3 Months	Maintain field sanitation; remove infected leaves; apply balanced fertilizers	Prevent early disease establishment
3–5 Months	Spray <i>Pseudomonas fluorescens</i> (0.5–1%) or <i>Bacillus subtilis</i> formulations at 15–20 day intervals	Biological suppression and ISR induction



Crop Stage	Management Practice	Purpose
5–7 Months	Continue leaf pruning and sucker management; monitor disease severity	Reduce inoculum buildup
During Humid/Rainy Periods	Apply protectant fungicides (mancozeb/chlorothalonil) at recommended intervals if disease pressure increases	Prevent spore germination
Severe Disease Conditions	Alternate systemic fungicides with protectant fungicides according to local recommendations	Disease containment and resistance management
Flowering to Bunch Development	Maintain at least 8–10 healthy functional leaves; continue sanitation measures	Support fruit filling and yield
Post-Harvest	Remove infected debris; compost residues; apply organic amendments and microbial inoculants	Reduce carry-over inoculum



Fig. 3. Seasonal Schedule for Integrated Management of Yellow Sigatoka



Zero-Waste Approaches in Vegetable Postharvest Technology

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Symptoms

Postharvest losses in vegetables represent a major challenge to global food security, sustainability, and environmental conservation. Approximately 20–40% of vegetables produced worldwide are lost during harvesting, handling, storage, transportation, processing, and marketing. The concept of zero-waste postharvest technology aims to maximize resource utilization, minimize losses, and convert agricultural by-products into valuable products. Modern approaches such as circular bioeconomy principles, valorization of vegetable waste, biodegradable packaging, renewable energy utilization, smart storage systems, and sustainable processing technologies contribute significantly to waste reduction. These strategies improve profitability, environmental sustainability, and food system resilience. This article explores recent developments, applications, challenges, and future prospects of zero-waste approaches in vegetable postharvest technology.

Keywords: Zero-waste technology, Vegetable postharvest management, Circular bioeconomy, Food loss reduction, Sustainable agriculture

Introduction

Vegetables are highly perishable commodities that undergo rapid deterioration after harvest. Significant losses occur due to improper handling, storage, transportation, and marketing practices. These losses not only reduce farmers' income but also contribute to environmental pollution and food insecurity. The zero-waste concept focuses on eliminating waste generation through efficient utilization of resources and recycling of by-products. In vegetable postharvest systems, zero-waste approaches aim to convert waste into value-added products while improving supply chain efficiency. Modern technologies and sustainable management practices are transforming conventional postharvest systems into environmentally responsible and economically viable models.



Concept of Zero-Waste Postharvest Technology

Zero-waste postharvest technology is based on the principle that every component of harvested vegetables should be utilized efficiently. Instead of disposing of damaged, surplus, or processing waste, these materials are redirected into useful applications. The approach emphasizes resource conservation, recycling, reuse, and recovery. It aligns with circular economy principles where waste from one process becomes a resource for another. Zero-waste systems reduce landfill disposal and greenhouse gas emissions. They improve sustainability throughout the vegetable value chain and promote responsible consumption and production practices.

Magnitude of Postharvest Losses in Vegetables

Vegetable losses occur at multiple stages including harvesting, grading, packaging, storage, transportation, and retail marketing. Mechanical damage, microbial spoilage, moisture loss, and physiological deterioration are major causes of losses. In developing countries, inadequate infrastructure further increases waste generation. These losses represent a significant waste of water, energy, labor, fertilizers, and land resources used during production. Reducing postharvest losses can substantially improve food availability without increasing agricultural land use. Therefore, minimizing waste is a key objective of sustainable postharvest management.

Valorization of Vegetable Waste

Vegetable waste contains valuable nutrients, fibers, pigments, antioxidants, and bioactive compounds. Instead of disposal, these by-products can be transformed into useful products. Carrot peels, tomato pomace, onion skins, cabbage leaves, and other residues serve as sources of functional ingredients. Vegetable waste can be processed into powders, extracts, natural colorants, dietary fiber supplements, and nutraceutical products. Valorization improves economic returns while reducing environmental impacts. It also supports the development of sustainable food processing industries and circular bioeconomy systems.

Production of Biofertilizers and Compost

One of the most effective zero-waste approaches is the conversion of vegetable residues into organic fertilizers. Composting transforms biodegradable waste into nutrient-rich soil amendments. Vermicomposting further enhances nutrient availability through earthworm activity. Vegetable processing waste can also be utilized for biofertilizer production using



beneficial microorganisms. These organic products improve soil health, nutrient cycling, and crop productivity. Composting reduces landfill waste and contributes to sustainable agricultural practices. It represents a simple and economically viable waste management strategy.

Bioenergy Generation from Vegetable Waste

Vegetable waste can serve as a renewable energy source through various bioenergy technologies. Anaerobic digestion converts organic residues into biogas, which can be used for heating, electricity generation, and cooking. Biomass gasification and bioethanol production are additional methods for energy recovery. Vegetable processing industries can utilize generated energy to reduce operational costs and carbon emissions. Bioenergy production supports waste minimization while contributing to renewable energy goals. This approach strengthens sustainability within agricultural and food systems.

Biodegradable Packaging from Vegetable By-Products

Vegetable residues can be utilized as raw materials for biodegradable packaging production. Cellulose, starch, pectin, and fiber extracted from vegetable waste are used to manufacture eco-friendly packaging materials. These biodegradable alternatives reduce dependence on petroleum-based plastics. Packaging materials produced from vegetable by-products provide environmental benefits while maintaining product quality. Such innovations support circular economy principles and sustainable packaging development. The integration of waste utilization with packaging technology represents an important advancement in zero-waste systems.

Smart Storage and Supply Chain Technologies

Modern storage technologies help reduce losses and improve resource efficiency. Controlled atmosphere storage, cold chain systems, and smart monitoring technologies minimize spoilage during storage and transportation. Internet of Things (IoT)-based sensors continuously monitor environmental conditions and alert managers to potential problems. Artificial intelligence helps optimize storage conditions and predict product deterioration. These technologies improve shelf life and reduce food waste throughout the supply chain. Smart management systems play a critical role in achieving zero-waste objectives.



Circular Bioeconomy in Vegetable Processing

The circular bioeconomy promotes sustainable utilization of biological resources through closed-loop systems. Vegetable processing industries increasingly adopt circular approaches where waste streams are converted into valuable products. Processing residues are utilized for food ingredients, animal feed, compost, bioenergy, pharmaceuticals, and biodegradable materials. This model minimizes waste generation while maximizing economic value. Circular bioeconomy strategies support environmental sustainability, resource efficiency, and industrial innovation. They represent the foundation of future zero-waste food systems.

Challenges in Implementing Zero-Waste Technologies

Despite numerous benefits, several challenges hinder the widespread adoption of zero-waste approaches. Limited infrastructure, high initial investment costs, and lack of technical expertise can restrict implementation. Efficient collection and segregation of vegetable waste remain logistical challenges. Regulatory frameworks for waste-derived products may vary among countries. Consumer awareness and acceptance also influence market success. Addressing these constraints requires policy support, technological innovation, and stakeholder collaboration. Continued research is essential for improving economic feasibility and scalability.

Future Prospects of Zero-Waste Postharvest Systems

The future of vegetable postharvest technology is increasingly focused on sustainability and resource efficiency. Advances in biotechnology, nanotechnology, artificial intelligence, and renewable energy systems will enhance waste utilization opportunities. Development of integrated biorefineries will enable the production of multiple value-added products from vegetable residues. Smart packaging and digital supply chains will further reduce losses. Government policies supporting circular economy initiatives will accelerate adoption. Zero-waste technologies will play a crucial role in achieving sustainable development goals and strengthening global food systems.

Conclusion

Zero-waste approaches in vegetable postharvest technology provide innovative solutions for reducing losses, improving sustainability, and maximizing resource utilization. Through waste valorization, composting, bioenergy production, biodegradable packaging, and smart storage technologies, vegetable residues can be transformed into valuable resources. These approaches



contribute to environmental conservation, economic growth, and food security. Although challenges remain, technological advancements and increasing awareness of sustainability are driving rapid progress. Adoption of zero-waste principles will be essential for developing resilient and environmentally responsible vegetable supply chains.

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The Hidden Nutritional Power of Wild Greens

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Introduction

Vegetables that grow naturally on grasslands and along the embankments of fields are called wild vegetables. Tribal communities living near forests and farm laborers who are familiar with these vegetables still use them as part of their traditional diet. These vegetables are easily available according to the season and form an integral part of their daily food. They are rich in medicinal properties. Around 14 such plants are used as remedies for diabetes, stomachache, cough and other ailments, while some are especially beneficial for pregnant women and children. People living in urban areas generally know little about these vegetables and their medicinal value, so they are used less often in the diet. This article provides information about some of these wild vegetables.

Elephant Foot Yam (Suran) :

Among tuber vegetables, Suran is considered the most superior because of its medicinal qualities, and is therefore known as "Kandanayak" i.e. King of Tubers. Its scientific name is *Amorphophallus paeoniifolius*. This plant is found in the forests of Vidarbha, Konkan and the Western Ghats. It is also cultivated in some places. Suran remains dormant for almost eight months of the year and grows vigorously only during the four months of the monsoon. The Suran tuber is a modified underground stem. At the end of summer or the beginning of the rainy season, this underground tuber emerges from dormancy and begins to grow.

Medicinal Properties :

- Suran is dry, astringent and pungent in nature. It stimulates appetite and improves taste. It is useful in asthma, bronchitis, vomiting, stomachache, piles, blood disorders, and elephantiasis.
- The fresh tuber acts as a stimulant, an expectorant and has restorative properties.



- Suran contains vitamins A, B, and C.
- It is beneficial for loss of appetite, indigestion, asthma, cough, intestinal worms and disorders of the liver and spleen.
- Applying a paste made from the tuber and seeds helps reduce swelling in arthritis.
- Curry made from Suran tuber is beneficial for piles. It constricts the blood vessels in hemorrhoids and is therefore especially useful in bleeding piles.
- Eating Suran curry improves liver function, promotes proper bowel movements and relieves constipation.
- In Ayurvedic medicine, Suran tuber powder is widely used. Formulations such as Brihat Surankabaya and Suranadivatak are prepared from Suran.

Chival:

Chival is locally known as Ranghol, Bhuichauli, Khatechaunal, Chivli, Lahan Ghol and Chhoti Ghol Tar. Its scientific name is *Portulaca quadrifida*. Chival grows as a weed in moist and waterlogged places, including fields and gardens. It is found throughout Maharashtra including Konkan, Western Maharashtra, Marathwada, Vidarbha and Khandesh as well as across India.

Medicinal Properties :

- The seeds of Chival are used in the treatment of inflammation of the kidneys and urinary bladder.
- The seeds have lubricating and diuretic properties.
- An infusion made from the seeds increases urine output.
- The juice of Chival is given to stop bleeding from the gums, in sputum and in urine.
- Chival is beneficial in the treatment of piles.
- The vegetable is cooling, absorbent, anti-inflammatory and blood-purifying.
- Chival helps reduce body heat and promotes proper urination.
- It relieves burning sensations during urination and burning in the hands, feet, and eyes.
- Recent research has shown that Chival contains compounds that act effectively on the nervous system and also possess anticancer properties.

**Ambadi:**

In scientific terminology, Ambadi is called *Hibiscus sabdariffa*. It is an Ayurvedic medicinal plant that grows in India. The leaves of Ambadi are used as a vegetable. This plant grows to about 1.5 to 2 meters in height and has an upright growth habit. Its leaves have a sour taste. The tender leaves are cooked as a leafy vegetable. This vegetable is rich in iron, vitamins K, A, and B6, folate, calcium, and zinc.

Medicinal Properties :

- Ambadi leaves help lower and regulate high blood pressure.
- They contain a large amount of antioxidants, which help reduce bad cholesterol and keep blood pressure under control.
- The vegetable is also used for weight management.
- Since it is rich in vitamin A, iron, and zinc, it is beneficial for eye health.
- Its high calcium content makes it important for strengthening bones.
- Because it contains a high amount of iron, it is useful for increasing blood levels.

Tandulja

This is an Ayurvedic medicinal plant that grows in India.

Medicinal Properties :

- Tandulja vegetable should be eaten as a source of vitamin C.
- It is rich in sweet-tasting properties and has a cooling potency.
- It is especially useful in fevers caused by excessive heat, particularly during measles, chickenpox, and recurrent fevers.
- It should definitely be included in the diet for conditions related to toxins, eye disorders, bile disorders, piles, liver diseases, and urinary stone formation.
- It is very useful for reducing inflammation and excess heat in leprosy and various skin disorders.
- It is especially beneficial for people with delicate constitutions, as well as postpartum women and pregnant women.



- It is very useful for eye disorders such as burning sensation, watery eyes, and sticky eyes.
- It improves the brightness of the eyes.
- In chronic constipation, Tandulja helps loosen and remove waste stuck in the intestines.
- Thin Tandulja curry is particularly beneficial for the health of elderly people.

Bamboo

Bamboo belongs to the grass family and has a lifespan of about one hundred years. Scientifically, it is known as *Bambusa arundinacea*. It is found in India, Sri Lanka, and Myanmar. In India, bamboo grows naturally in the forests of Gujarat, Maharashtra, Karnataka, and Kerala. In Maharashtra, it is mainly found in the Konkan and Western Ghats regions, as well as in Khandesh and Vidarbha. Bamboo is a perennial, tall, straight-growing plant that grows in clusters, forming bamboo groves. It commonly grows along the banks of streams and rivers.

Medicinal Properties :

- The roots, leaves, seeds, tender shoots, and bamboo silica (Vanshlochan) are used medicinally.
- Bamboo silica formed in the nodes of the stem is cooling, nutritious, and considered an aphrodisiac.
- It is highly beneficial for cough, tuberculosis and asthma.
- It also acts as a stimulant and fever reducer.
- It helps reduce skin inflammation associated with respiratory disorders and can stop bleeding through phlegm.
- Its bark is useful for treating rashes.
- Bamboo seeds are dry and heating in nature and are beneficial in the diets of obese individuals and people with diabetes.
- A decoction made from tender bamboo shoots or young leaves is given during childbirth to promote uterine contractions.



- It also helps expel postpartum discharge and regulates its flow.
- For diarrhea in cattle, bamboo leaves and black pepper are given together with salt.
- Pickle and curry prepared from tender bamboo shoots are beneficial for indigestion. They improve appetite and digestive power.
- Crushed tender bamboo shoots are applied as a poultice for swollen joints.

Bhokar

Bhokar is a plant found throughout Maharashtra. Bhokar trees grow naturally in forests across the Western Ghats, Satpuda, Konkan, and many other regions, and in some places they are also cultivated. Its scientific name is *Cordia dichotoma*. Bhokar is an evergreen tree that grows up to 10–12 meters tall. The fruits are round, shiny, about the size of jujubes and turn yellowish or pinkish-yellow when ripe. They contain 1 to 4 seeds. The fruits are filled with a sticky, mucilaginous pulp. Because of this, Bhokar is also called the "Indian Blue Berry."

Medicinal properties :

- The fruits and the tender leaves of Bhokar are cooked as a vegetable and are also made into pickles.
- The fruit curry is useful in treating diarrhea.
- It strengthens the intestines and promotes nourishment. Bhokar pickle is very tasty and is especially popular in Rajasthan, Gujarat, and Maharashtra.
- Bhokar pickle stimulates digestion, increases appetite and aids digestion.
- A vegetable made from Bhokar leaves is beneficial for bleeding disorders caused by excess heat in the blood.
- A decoction made from ripe Bhokar fruit, Adulsa leaves and Baheda fruits in equal proportions is given for cough.
- The bark of Bhokar is ground in water and given to treat diarrhea.

Bhui Amla

Bhui Amla is an annual herbaceous plant that grows 20–50 cm tall. It belongs to the Euphorbiaceae (castor) family. Its scientific name is *Phyllanthus amarus*. It grows abundantly



during the rainy season in fields, gardens, wastelands, and under all climatic conditions. It flowers and fruits from July to October and dries up after November and December. It can be propagated through seeds.

Medicinal properties :

- This plant contains a compound called "phyllanthin."
- In cases of jaundice, the plant is ground and given with milk in the morning and evening.
- It is also used to reduce enlargement of the liver and spleen.
- Bhui Amla increases urine output and reduces inflammation.
- Consuming this vegetable is beneficial for reduced urination, urinary stones, urinary infections, and related disorders.
- It has also been found useful in hepatitis B and jaundice associated with liver dysfunction.

Pathari

Pathari is a herbaceous plant found everywhere. It grows about 60–170 cm tall. Its scientific name is *Lindernia procumbens*.

Medicinal properties :

- The whole plant (all five parts) is used medicinally.
- Pathari is bitter, cooling, lubricating, absorbent, and promotes breast milk production.
- The juice of the plant mixed with licorice increases breast milk in nursing mothers.
- This mixture is also useful for dry cough.
- Feeding Pathari as fodder to livestock increases milk production.
- A vegetable made from its leaves is useful in chronic skin diseases and improves digestion.
- It is highly beneficial in jaundice and liver disorders.
- The vegetable is cooling but slightly bitter and helps reduce excess bile (pitta).



Bharangi

Bharangi belongs to the Verbenaceae family, the same family as Nirgundi. Its scientific name is *Clerodendrum serratum*. It is a perennial shrub that grows 3–5 feet tall. It is commonly found on hill slopes, scrub forests, riverbanks, and agricultural fields.

Medicinal properties :

- The root is used in treating fever and disorders associated with excess phlegm.
- It is especially used for asthma and cough caused by excessive phlegm.
- For colds and throat dryness, the root is given with dry ginger or sweet flag.
- For asthma, a decoction of Bharangi root, licorice, Baheda, and Adulsa leaves is administered.
- A vegetable made from Bharangi leaves is eaten to help prevent asthma.
- It is useful for colds, cough, fever, and chest congestion.
- Since the tender leaves aid digestion, they help cleanse the bowels.
- For intestinal worms, the leaves are boiled, and the strained water is consumed.

Mayalu

Mayalu is a perennial climbing vine cultivated in gardens, courtyards, backyards, and pots. It is found in tropical regions of Asia and Africa. It is also known as Velbondi, Indian Spinach, and Malabar Nightshade. Its scientific name is *Basella alba*. There are two varieties: red and white. It belongs to the Basellaceae family.

Medicinal properties :

- The tender leaves are used as a vegetable.
- It is recommended when there is excessive heat in the blood or bile.
- This vegetable has cooling properties.
- Like spinach, it is easy to digest. It helps reduce joint pain and swelling.
- It lowers excessive heat in the blood, purifies the blood, and thereby helps reduce skin disorders.



- It is also beneficial for hemorrhoids.
- The plant is astringent, slightly sweet, unctuous, sleep-inducing, mildly intoxicating, aphrodisiac, fat-promoting, laxative, and appetite-stimulating.
- It pacifies excess bile and is useful for skin diseases, dysentery, and wounds.
- It also has expectorant, nourishing, and fever-reducing properties.

Tarota

Tarota belongs to the Caesalpiniaceae family. Its scientific name is *Cassia tora*. It is a herbaceous plant growing 1–2 feet tall. In some regions, it is locally known as Takala or Taravata. It grows as a weed in wastelands, farms, gardens, forests, and along roadsides. When roasted, its seeds give off a coffee-like aroma.

Medicinal properties :

- The leaves contain purgative compounds and a red pigment.
- The plant contains the glucoside "emodin."
- Tarota has mild laxative properties and mainly acts on the skin.
- It is used for all types of skin diseases, especially when the skin becomes thickened.
- A vegetable made from the leaves is consumed for skin disorders, while the seeds are ground into a paste for external application.
- Traditionally, the seeds are mixed with lemon juice before use.
- A paste made from the roots and lemon juice is used for ringworm.
- The leaves and seeds contain chrysogenic acid, which is valuable in treating skin diseases.
- The leaves are anti-parasitic and mildly laxative.
- A decoction of the leaves is given to children for fever during teething.
- The leaf juice mixed with honey is used for bile disorders, heart disease, asthma, and cough.



Kena

Kena, scientifically known as *Commelina benghalensis*, is easily recognized. It is found throughout Maharashtra. It spreads abundantly over the ground from the rainy season until October. This plant is a rich source of vitamins and minerals.

Medicinal properties :

- The leaf juice is useful for diarrhea.
- Consuming this vegetable helps relieve sore throat, throat pain, eye disorders, skin diseases and burning sensations.
- Eating the vegetable or drinking its juice helps reduce the severity of jaundice.
- Consuming the root juice helps alleviate stomach disorders.

Punarnava

Punarnava is used to prepare the medicinal fermented formulation known as Punarnavasava. A decoction of Punarnava along with deodar, dry ginger, and vetiver is considered effective for swelling in any part of the body. Some people apply an eye ointment made by grinding the root of white Punarnava in fermented rice water to treat night blindness. If there is frequent urination, taking 20–40 ml of Punarnava decoction twice daily is believed to be beneficial. The roots of white Punarnava ground in milk are also traditionally given for fevers occurring every fourth day.

Ghol

This vegetable is useful in reducing hemorrhoids. It also promotes clear and abundant urination.

Alu (Taro)

The juice of its leaves and stems has antiseptic properties. Applying the juice to cuts and bandaging the area helps wounds heal faster. Taking the juice with sugar two or three times a day is believed to reduce hemorrhoids.



Suran



Chival



Ambadi



Bhokar



Bamboo



Tarota



Pathri



Mayalu



Alu



Bharangi





Bhringraj: A Promising Medicinal Crop for Healthcare and Economic Development

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Introduction

Medicinal plants have been an integral part of human healthcare since ancient times, providing natural remedies for maintaining health and treating various ailments. Among these valuable herbs, Bhringraj (*Eclipta alba* L.), popularly known as the “King of Hair Care Herbs,” occupies a prominent place in traditional Ayurvedic medicine. For centuries, it has been valued for promoting healthy hair growth and supporting overall well-being. Beyond its reputation as a hair tonic, Bhringraj possesses remarkable medicinal properties that benefit the liver, skin, immune system, and digestive health. With the growing global interest in herbal medicines, natural cosmetics, and plant-based healthcare products, Bhringraj is emerging as an important medicinal plant with significant therapeutic, commercial, and economic potential.

Botanical Profile of Bhringraj

Bhringraj belongs to the family Asteraceae and is a small annual herb commonly found in moist and marshy habitats. The plant typically grows to a height of 30–60 cm and bears small white flower heads. It is widely distributed throughout India and many tropical and subtropical regions of the world. Bhringraj thrives under warm and humid climatic conditions and adapts well to a variety of soil types. Its ease of cultivation, short crop duration of about 90 days, and adaptability make it a suitable crop for commercial cultivation as well as small-scale farming.





Bhringraj (*Eclipta alba* L.)

A Treasure Trove of Bioactive Compounds

The medicinal significance of Bhringraj is largely attributed to its rich reservoir of bioactive compounds. The plant contains important phytochemicals such as wedelolactone, demethylwedelolactone, ecliptine, flavonoids, polyacetylenes, alkaloids, triterpenes, and phenolic compounds. These constituents exhibit a wide range of biological activities, including antioxidant, anti-inflammatory, antimicrobial, hepatoprotective, and immunomodulatory effects. Owing to these pharmacological properties, Bhringraj has been extensively used in traditional medicine and is increasingly attracting scientific attention for its therapeutic applications.

Bhringraj: The King of Hair Care Herbs

Among its many benefits, Bhringraj is best known for its positive effects on hair health. Ayurvedic practitioners have long recommended the herb for managing hair fall, thinning hair, premature greying, dandruff, dry scalp, and weak hair roots. Bhringraj oil, one of the most popular herbal hair formulations, nourishes the scalp, improves blood circulation, and strengthens hair follicles. Regular use is believed to promote healthy hair growth, improve hair texture, enhance thickness, and restore natural shine. These properties have made Bhringraj a key ingredient in numerous herbal oils, shampoos, conditioners, and hair care products.

A Natural Protector of Liver Health

The liver plays a vital role in detoxification, metabolism, and overall health, and Bhringraj has traditionally been recognized as an effective liver-supporting herb. It helps protect liver cells from damage caused by toxins, oxidative stress, and environmental pollutants. In traditional medicine, Bhringraj has been widely used for the management of jaundice, hepatitis, fatty liver disorders, and other liver-related ailments. Modern scientific studies have further validated its hepatoprotective properties, highlighting its potential as a natural remedy for maintaining liver function and supporting liver health.

Promoting Healthy and Radiant Skin

Bhringraj also contributes significantly to skin health due to its antimicrobial, anti-inflammatory, and antioxidant properties. Herbal preparations containing Bhringraj are commonly used to promote wound healing, soothe skin irritation, reduce inflammation, and manage minor skin infections. The antioxidants present in the herb help neutralize free radicals



that cause cellular damage, thereby supporting healthy skin regeneration and maintaining skin vitality. As a result, Bhringraj is increasingly being incorporated into herbal skincare formulations.

Supporting Overall Health and Well-being

The health benefits of Bhringraj extend far beyond hair, liver, and skin care. The herb helps strengthen the body's immune system and enhances resistance to infections. In Ayurveda, it is regarded as a rejuvenating herb that promotes mental calmness, helps manage stress, and supports overall wellness. Its antioxidant compounds protect cells from oxidative damage, contributing to healthy aging and improved physiological functioning. Additionally, Bhringraj has traditionally been used to support digestion and metabolic processes, making it a valuable herb for maintaining overall health.

Cultivation Potential and Commercial Opportunities

The increasing demand for herbal medicines, nutraceuticals, and natural cosmetic products has significantly enhanced the commercial importance of Bhringraj cultivation. The crop can be grown successfully in tropical and subtropical regions with adequate moisture and favorable environmental conditions. Farmers are increasingly recognizing Bhringraj as a profitable medicinal crop because of its short crop duration, relatively low cultivation cost, high medicinal value, and suitability for organic farming systems.

The rising consumer preference for herbal and organic products has created a strong market demand for Bhringraj. Its dried herbs, extracts, and processed products are extensively utilized by pharmaceutical, cosmetic, and herbal industries, providing excellent opportunities for income generation, crop diversification, and sustainable agricultural development.

Value Addition and Economic Importance

Bhringraj has emerged as an important raw material for the herbal industry. A wide range of value-added products, including herbal oils, shampoos, hair masks, capsules, powders, extracts, and dietary supplements, are manufactured using Bhringraj. The growing global shift toward natural and plant-based healthcare products offers promising opportunities for farmers, entrepreneurs, women self-help groups, and small-scale industries to engage in cultivation, processing, and marketing of Bhringraj-based products. Developing high-quality herbal formulations can substantially enhance profitability while promoting sustainable and eco-friendly agricultural practices.



Bhringraj is a remarkable medicinal herb that successfully bridges traditional wisdom and modern scientific research. Revered as the “King of Hair Care Herbs,” it offers a wide range of health benefits, including support for hair growth, liver protection, skin health, immunity, and overall well-being. At the same time, its increasing demand in herbal medicine, cosmetics, and wellness industries has enhanced its commercial value and cultivation potential. As awareness of natural healthcare continues to grow, Bhringraj has the potential to play an increasingly important role in promoting human health, supporting rural livelihoods, and advancing sustainable medicinal plant cultivation.





ROOTS AS SOURCE & SINK FOR ORGANIC COMPOUNDS & PLANT HORMONES

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Introduction

Roots are integral components of plants responsible for various functions, including anchorage, absorption of water and nutrients and synthesis and storage of organic compounds and plant hormones. Roots serve as sources and sinks for these substances, playing crucial roles in plant growth, development and response to environmental stimuli.

ROOTS AS SOURCE

1. PHOTOSYNTHESIS:

Plants use photosynthesis primarily in their leaves, but they also have chloroplasts in their roots, which convert light energy into chemical energy in the form of carbohydrates. Roots have limited photosynthetic activity due to their underground location and lack of light penetration. They obtain carbon dioxide from the soil, which may hinder their photosynthetic activity. Roots are the main organelles in the soil that take up water and may prioritize water intake over photosynthesis in situations of water scarcity.

Root photosynthesis contributes to the synthesis of organic molecules, particularly sugars, which are crucial for root growth and metabolism. These sugars can be transferred to other areas of the plant for development, growth and energy storage. Root photosynthesis also plays a role in stress responses, providing energy to sustain plant life when aboveground tissues are damaged or shaded. It can also boost a plant's resilience in conditions like excessive soil salinity or flooding, where aboveground tissues may be stressed.



2. PRIMARY METABOLITES:

Roots actively synthesize amino acids, building blocks of proteins, through various metabolic processes. The 'amino acid biosynthesis pathway' is a major process, involving several enzymatic steps to produce various amino acids, such as tryptophan, phenylalanine and tyrosine. Fatty acids, also produced by roots, store energy and are crucial parts of membrane lipids. They are primarily produced via the 'fatty acid synthesis pathway' (de novo fatty acid synthesis), which converts acetyl-CoA into long-chain fatty acids like palmitic acid.

Organic acids are produced through various metabolic processes, such as the 'tricarboxylic acid (TCA) cycle' or the citric acid cycle or the Krebs cycle. The oxidation of acetyl-CoA from different carbon sources yields carbon dioxide, ATP and reducing equivalents (NADH and FADH). The synthesis of several organic acids begins with intermediates like citrate, malate and oxaloacetate.

Metabolic pathways play a role in the production of amino acids, with glycolysis converting glucose to pyruvate, producing ATP and reducing equivalents (NADH). The mitochondrial TCA cycle acts as a center for the oxidation of acetyl-CoA, resulting in the synthesis of ATP, NADH and FADH₂.

Roots produce amino acids through specific biosynthetic routes, ensuring the availability of essential building blocks for protein synthesis and other biological functions. The integration of metabolic pathways ensures the effective use of resources and adaptation to changing environmental conditions.

3. SECONDARY METABOLITES:

Roots produce various secondary metabolites, including alkaloids, flavonoids and terpenoids, which serve various biological functions. Alkaloids are nitrogen-containing molecules produced through various pathways, such as shikimate, mevalonate and non-mevalonate and are used as defensive mechanisms against infections and herbivores. Flavonoids, a class of polyphenolic chemicals, are produced from phenylalanine via the phenylpropanoid pathway and are involved in various biological processes. They function as antibacterial and antifeedant substances, aiding in plant defense against diseases and herbivores.

Terpenoids, a broad class of chemicals derived from the condensation of isoprene units, are produced by roots through the mevalonate pathway. They have allelopathic properties that



draw in pollinators and other beneficial species. Examples of terpenoids include VOCs, diterpenes and triterpenoids.

Secondary metabolites in roots serve several roles, including defense against herbivores and pathogens, attraction of beneficial organisms and allelopathy. Root-based alkaloids, flavonoids and terpenoids can act as allelochemicals, acting as antibacterial agents against soil-borne diseases and interfering with herbivore feeding behavior. They also attract nitrogen-fixing bacteria and mycorrhizal fungus, enhancing plant health and production.

Allelopathy occurs when roots discharge secondary metabolites into the soil, affecting the growth and development of nearby plants. Producing plants can gain a competitive edge by preventing rival plant species from germinating and growing.

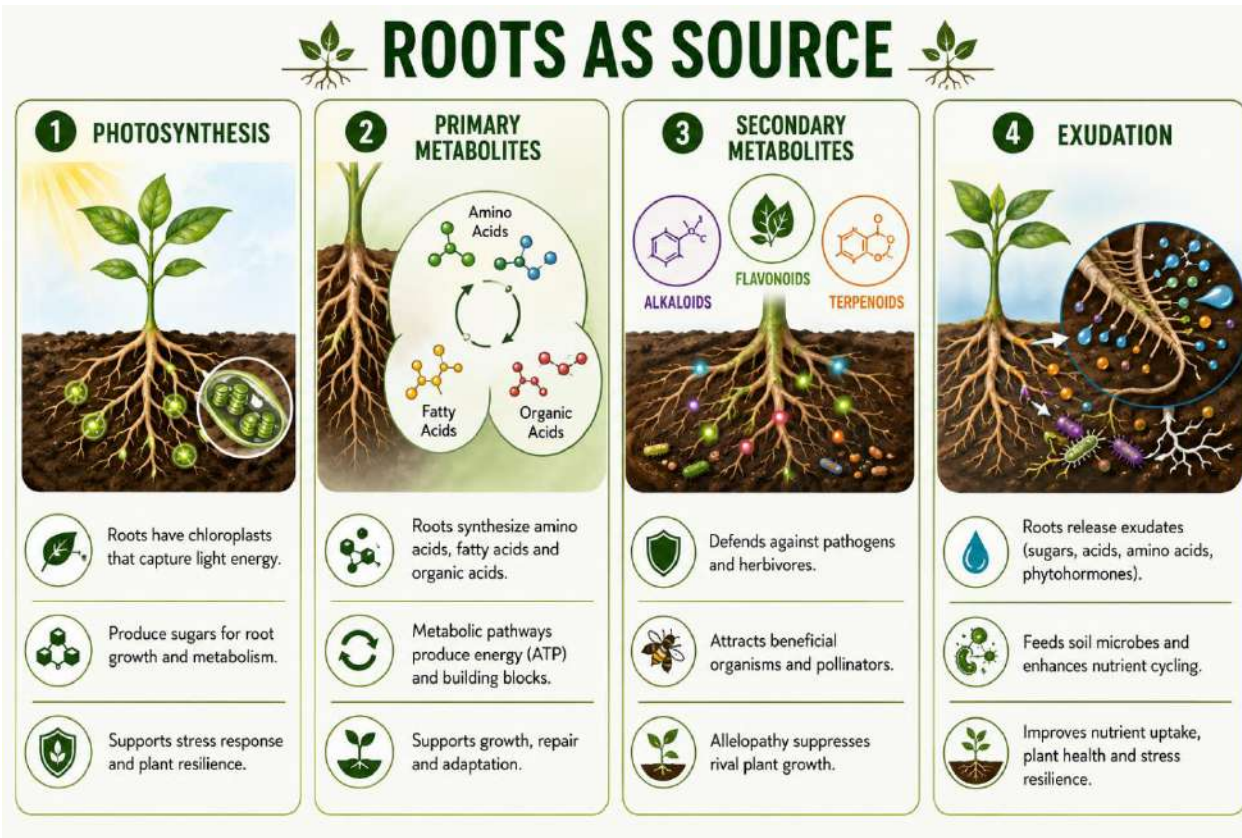
4. EXUDATION:

Root exudates are organic substances released by plant roots into the soil, containing sugars, organic acids, amino acids and phytohormones. Factors influencing root exudation include plant species, developmental stage, environmental factors, soil nutrient availability and interactions with soil microbes. Plants may change the makeup and volume of exudates in response to biotic and abiotic challenges, nutritional shortages and interactions with nearby plants and microorganisms.

Root exudates have several functions, including nutrient acquisition, microbial interactions, plant-microbe interactions, rhizosphere modification and allelopathy. They support the growth and activity of diverse microbial communities in the rhizosphere, including bacteria, fungi and archaea. These microbes contribute to nutrient cycling processes, such as organic matter decomposition, nitrogen fixation and phosphorus solubilization.

Exudates enhance nutrient cycling by mobilizing nutrients in the soil, facilitating their uptake by roots and microbial assimilation into biomass. Compounds like organic acids and amino acids can increase the availability of phosphorus, iron and other micronutrients by chelating soil minerals and promoting their release into the soil solution.

Root exudates also influence plant health and productivity by promoting beneficial interactions with symbiotic microbes and suppressing the growth of pathogenic microbes. Phytohormones present in exudates can modulate plant growth and development, root architecture and stress responses, contributing to plant resilience and adaptation to environmental challenges.



ROOTS AS SINK

1. NUTRIENT UPTAKE:

Roots play a crucial role in absorbing water and essential nutrients from the soil through specialized structures like root hairs, epidermal cells and root cortex. This process involves the uptake of both macronutrients (required in large quantities) and micronutrients (required in smaller quantities) essential for plant growth and development.

Macronutrients include nitrogen (N), phosphorus (P), potassium (K), iron (Fe), zinc (Zn) and copper (Cu). Roots absorb these nutrients as phosphate ions, which are often bound to soil particles. Potassium plays a role in enzyme activation, osmotic regulation and stomatal movement.

Micronutrients are essential for metabolic processes, enzyme activities and electron transfer reactions. Roots absorb micronutrients as ions, often through specific transporters and carrier proteins. Active uptake mechanisms, which require energy (ATP) and specific transport proteins embedded in the plasma membrane of root cells, ensure efficient uptake even when soil nutrient concentrations are low.



Roots serve as temporary storage sites for nutrients, particularly in the form of ions or complex molecules like sugars, amino acids and organic acids. During periods of high demand or limited nutrient availability, roots can mobilize stored nutrients and redistribute them to actively growing tissues.

Roots contribute to nutrient cycling within the plant-soil system by continuously absorbing, assimilating and releasing nutrients back into the soil through root exudation, root turnover and decomposition of root biomass. This process ensures the recycling of essential nutrients, maintaining soil fertility and supporting plant growth.

2. STORAGE ORGANS:

Plants store reserve carbohydrates, primarily in the form of starch, within specialized root tissues. Starch is a polysaccharide composed of glucose molecules and serves as a long-term energy reserve for plants. Roots have specialized storage structures where starch accumulates, such as tubers, taproots and storage roots. Starch synthesis occurs through the conversion of glucose-6-phosphate into starch granules within plastids, specifically amyloplasts, in root tissues. These granules accumulate within specialized storage cells or parenchyma cells in the cortex or pith of the root.

Root carbohydrate storage is significant for several reasons. It serves as an energy reserve for plants during periods of low photosynthetic activity, such as winter dormancy or adverse environmental conditions. It also supports growth and development by providing energy for cell division, elongation and differentiation, supporting root growth and development. Additionally, stored carbohydrates contribute to reproductive success by providing energy for flowering, fruit development and seed production.

Root carbohydrate storage is a survival strategy for perennial plants, enabling them to endure unfavorable conditions and resume growth when conditions improve. Plants with storage roots, such as sweet potatoes, can survive seasonal fluctuations in environmental conditions by relying on stored reserves during dormancy or adverse weather.

3. HORMONE ACCUMULATION:

Auxins, cytokinins, gibberellins and ethylene are essential hormones in plant growth and development. Auxins are synthesized in the shoot apical meristem and transported downwards to roots, while cytokinins are synthesized in various tissues and transported acropetally to shoots. They play crucial roles in regulating cell division, differentiation and root meristem



activity in roots. Gibberellins are synthesized in young developing leaves and seeds and transported to roots through the vascular system. They regulate cell elongation, root hair development and responses to abiotic stresses like drought and salinity.

Absciscic acid (ABA) is synthesized in response to environmental stresses and is transported to roots from the shoot. It regulates physiological processes in roots, including stomatal closure, root growth inhibition under water stress and the induction of root dormancy. ABA also mediates responses to abiotic stresses by regulating gene expression and cellular processes in root tissues.

Ethylene is synthesized in various tissues, including roots and can act locally or be transported to other parts of the plant. In roots, it regulates processes such as root hair elongation, adventitious root formation and responses to mechanical stress and flooding. Ethylene interacts with other hormones like auxins and cytokinins to modulate root growth and development.

Hormones play a significant role in plant growth and development, with auxins, cytokinins, gibberellins, ethylene and auxins playing key roles in root development.

4. SIGNAL TRANSDUCTION:

Roots have specific receptors for plant hormones, such as auxins, cytokinins, gibberellins, absciscic acid and ethylene, which can perceive environmental signals. These hormones initiate signal transduction pathways within root cells, affecting gene expression, protein activity and cellular responses. Root responses to these hormones are influenced by environmental cues like light, temperature, water availability, nutrient status and biotic interactions. Root architecture is regulated by auxins and gibberellins, which promote root growth and elongation, while cytokinins can inhibit root growth. Auxins play a central role in lateral root formation and environmental signals can modulate auxin distribution and lateral root initiation. Nutrient uptake is regulated by auxins and cytokinins, which can optimize nutrient uptake in response to fluctuating soil levels. Abiotic stress responses, such as drought, salinity and flooding, are mediated by absciscic acid and ethylene, which are integrated with stress-responsive gene expression networks.

Root hormonal signaling pathways also mediate interactions with beneficial microbes, influencing symbiotic associations and nutrient acquisition strategies.

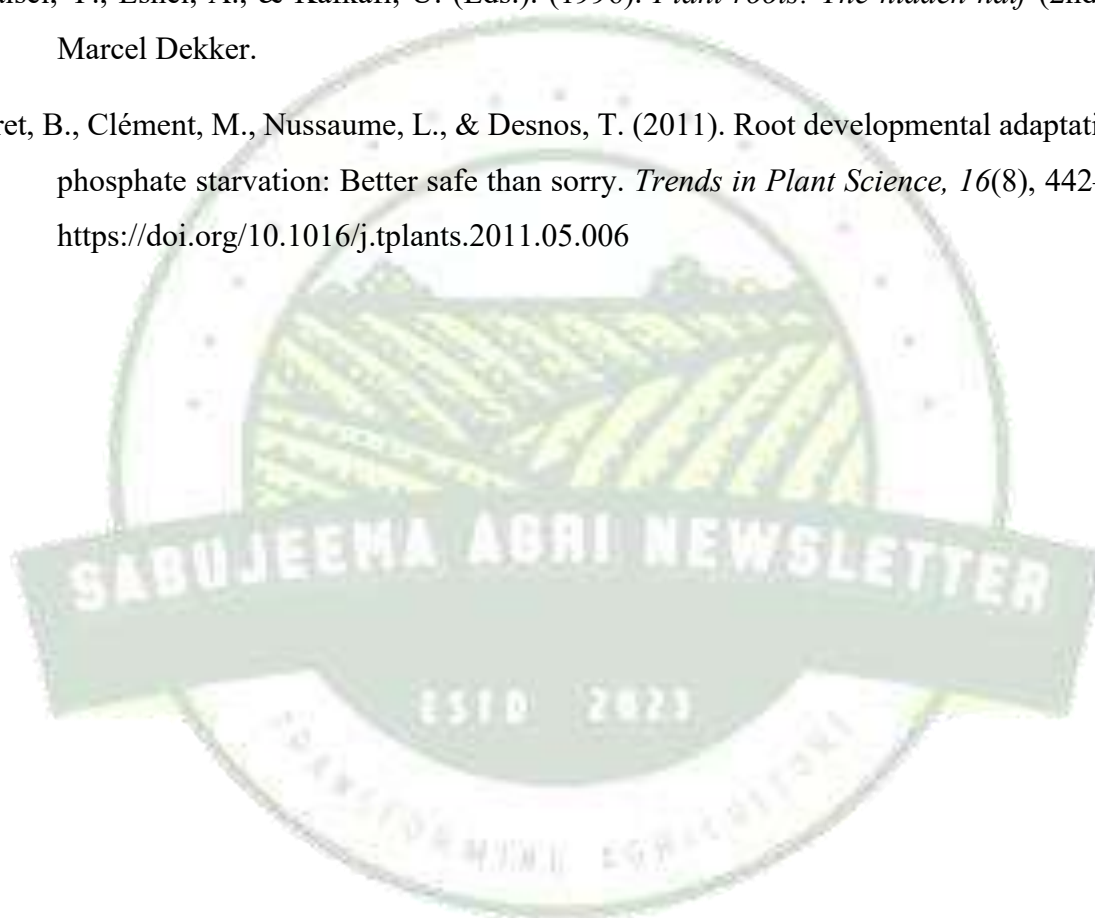


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Solar Aeration Methods for Fish Farms: Economic and Environmental Benefits Across Extensive, Semi-Intensive and Intensive Culture Systems

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Introduction

Dissolved oxygen is the single most limiting water-quality factor in pond-based fish culture, and unplanned oxygen depletion remains one of the commonest causes of stress, disease outbreaks and mass mortality in stocked ponds. Motorised, grid- or diesel-powered aerators are well established in intensive and semi-intensive shrimp and fish farms, but their high running cost and dependence on uninterrupted electricity or fuel supply keep them out of reach for the great majority of small, rain-fed and bore-well-fed village ponds, which are mostly extensive or semi-intensive carp ponds or mixed carp-tilapia-pacu polyculture systems. Solar aeration offers a low running-cost, low-carbon alternative that can be scaled from a small battery-backed air pump for a backyard pond to a solar paddle-wheel unit for a one-hectare grow-out pond. This article reviews the classification of fish farming systems by input intensity, explains why aeration is important in pond aquaculture, summarises the common motorised aerator types and their approximate costs, and discusses how solar and other renewable aeration methods can be adapted to extensive, semi-intensive and intensive farms alike, with particular emphasis on their relevance to rain-fed and bore-well ponds in rural India.

Keywords: Solar aeration, Dissolved oxygen, Extensive aquaculture, Semi-intensive aquaculture, Paddle wheel aerator, Renewable energy



Introduction

The Inland fisheries and Aquaculture Production of India reached 151.6 Lakh Tonnes in 2025 and the freshwater fishes especially Indian Major Carps (Catla, Rohu & Mrigal) remain the backbone of inland aquaculture constituting 54% of total inland production. As farmers intensify stocking to raise per-hectare production, the natural capacity of a pond to replenish oxygen through photosynthesis and surface diffusion is quickly outpaced by the Biological Oxygen Demand (BOD) created by fish respiration, feed residues, plankton respiration at night and the decomposition of organic matter on the pond bottom. Mechanical aeration was developed to close this gap, and it is now considered essential in commercial semi-intensive and intensive fish farms. However, most rural pond owners still rely entirely on natural aeration, leaving their ponds vulnerable to sudden oxygen crashes, particularly during cloudy, low-wind weather or algal die-off events. This article discusses aeration needs across the three broad categories of fish farming by input intensity, reviews conventional motor-driven aerators and their costs, and makes the case that solar-powered aeration is particularly well suited to rain-fed and bore-well-fed ponds that presently have no aeration at all.



Extensive, Semi-Intensive and Intensive Fish Farming Systems

Fish farming systems are broadly classified according to stocking density, feed and input use, and the degree of management intervention:

- **Extensive systems** rely almost entirely on the natural productivity of the pond. Stocking densities are low, supplementary feed is minimal or absent, and fertilisation (organic manure) is the main input used to boost natural food organisms. Most village tanks, seasonal rain-fed ponds and community ponds stocked with Indian major carps fall into this category.
- **Semi-intensive systems** use a combination of natural pond productivity and supplementary feeding, along with fertilisation, liming and periodic water exchange.



Stocking densities are moderate, and this is the most common system practised by small and marginal farmers who culture carps alone or in polyculture with tilapia and pacu.

- **Intensive systems** depend on high stocking densities, complete pelleted feed, active water quality management and mechanical aeration as a non-negotiable input. Biofloc systems, high-density monoculture ponds and most commercial shrimp farms fall under this category.

Parameter	Extensive	Semi-intensive	Intensive
Stocking density	Low (natural carrying capacity)	Moderate	High
Feed input	None / farm-made supplementary	Supplementary + some pelleted feed	Complete pelleted feed
Water source	Rain-fed / seasonal	Rain-fed, bore-well or canal	Assured bore-well / canal / RAS
Typical species	Indian major carps	Carps + tilapia + pacu polyculture	Monoculture carp / tilapia / shrimp
Aeration practice	Rarely used	Rarely to occasionally used	Essential, continuous

Table 1. Comparison of extensive, semi-intensive and intensive fish farming systems

Importance of Aeration in Fish Ponds

Dissolved oxygen (DO) is required by fish for respiration, by beneficial bacteria for the breakdown of organic waste, and by the pond ecosystem as a whole for maintaining water quality. In a still pond, oxygen is produced mainly by phytoplankton photosynthesis in the surface layer during daylight hours and is consumed continuously by fish, plankton and bottom sediments. Because photosynthesis



Figure 1. Relative stocking intensity across fish farming systems (illustrative)



stops at night while respiration continues, DO typically falls to its lowest point just before dawn, and this pre-dawn oxygen crash is the single most common trigger for fish kills in poorly managed ponds.

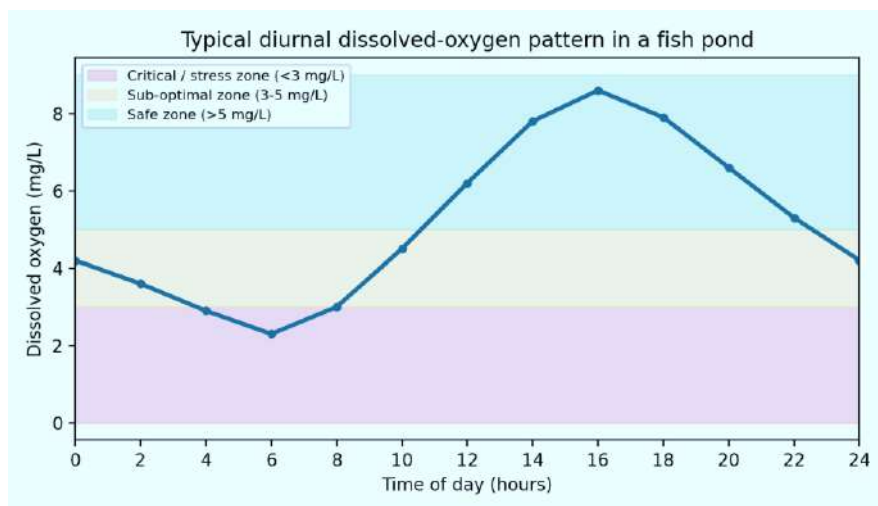


Figure 2. Typical diurnal dissolved-oxygen pattern in a fish pond, showing the pre-dawn low

Aeration helps in several ways:

- Prevents thermal and oxygen stratification by mixing surface and bottom water layers.
- Maintains DO above the stress threshold (commonly cited as around 3-4 mg/L for carps) during the critical early morning hours.
- Speeds up the breakdown of ammonia, hydrogen sulphide and other toxic metabolites that accumulate at the pond bottom.
- Allows farmers to safely increase stocking density and feeding rate, improving production per unit area.
- Reduces the risk of sudden mass mortality during cloudy weather, algal die-off or heavy overnight cloud cover.

Because of these benefits, aeration is treated as a core input in intensive and commercial semi-intensive farms. In extensive and low-input semi-intensive village ponds, however, aeration is very rarely used, mainly because of the cost and unreliability of grid power in rural areas.



Types of Motorised Aeration Used in Fish Ponds

Several types of electrically or diesel-driven aerators are used in commercial aquaculture, differing in the way they transfer oxygen into water:



1. **Paddle-wheel aerators:** The most widely used type in Indian shrimp and fish farms.

A motor-driven wheel with paddles splashes water into the air, increasing the air-water contact surface. Available in 1 HP, 2 HP and 3 HP models with two to twelve paddles.



2. **Aspirator / propeller-aspirator-pump (PAP) aerators:** Draw air through a hollow shaft and expel a mixture of air and water, useful in deeper ponds.

3. **Diffused air / air-blower systems:** A surface-mounted blower forces air through submerged perforated pipes or diffuser stones, releasing fine bubbles from the pond bottom; suited to deeper, biofloc and RAS tanks.

Cost and Running Expenses of Motorised Aerators

The capital cost of motorised aerators varies with horsepower and builds quality. A 1 HP paddle-wheel aerator is typically priced in the range of about Rs. 25,000-33,000, while 2 HP and 2.5-3 HP units with additional paddles and heavier frames cost roughly Rs. 37,000-67,000 depending on the manufacturer and number of paddles. Beyond the initial purchase, the recurring running cost is the real burden for small farmers: a 1 HP aerator run on grid electricity for eight hours a day consumes a substantial amount of power over a culture cycle, and where grid supply is unreliable, farmers must fall back on diesel gensets, which cost considerably more to run per unit of energy than grid power. On-going maintenance of gearboxes, bearings and motor windings adds a further recurring cost. For a two- to three-acre extensive or semi-intensive carp pond earning modest annual returns, this scale of recurring expenditure is difficult to justify, which is a key reason aeration remains largely absent from rural pond aquaculture.

Aerator type	Typical capacity	Approx. capital cost (INR)	Power source
Paddle-wheel (2-4 paddle)	1 HP	25,000 - 33,000	Grid / diesel genset
Paddle-wheel (6-8 paddle)	2-2.5 HP	37,000 - 49,500	Grid / diesel genset



Paddle-wheel (heavy duty)	3 HP	55,000 - 67,000	Grid / diesel genset
Diffused-air blower system	0.5-2 HP	15,000 - 40,000	Grid electricity

Table 2. Indicative capital cost of common motorised aerators

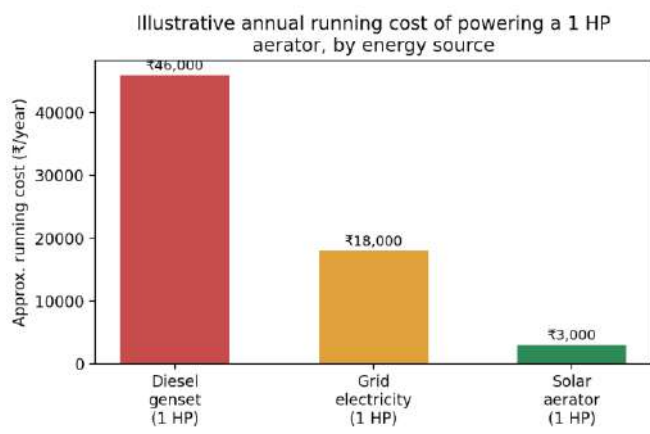


Figure 4. Illustrative annual running cost of powering a 1 HP aerator from different energy sources

Aeration in extensive or low-input semi-intensive fish ponds

The vast majority of fish farming in Indian villages is carried out in extensive or low-input semi-intensive ponds stocked with Indian major carps alone, or in mixed polyculture with tilapia and pacu. These ponds are typically rain-fed or fed by a bore-well, cover a small area, and are managed by farmers with limited capital. Grid electricity in many rural areas is intermittent, and running a diesel genset for several hours a day is expensive relative to the value of the crop. As a result, even though sudden overnight oxygen depletion is a recognised risk in these systems, particularly at the end of the culture cycle when biomass is highest, most village ponds continue to depend entirely on natural aeration. This gap is precisely where low-cost, low-maintenance renewable aeration options have the greatest potential to help.

Solar and Other Alternate Aeration Methods Suitable for All Farm Types

Several non-conventional aeration options can be adapted across extensive, semi-intensive and intensive systems, and are particularly attractive for ponds with no reliable grid connection:



- **Solar paddle-wheel aerators:** A solar panel and battery bank power a DC motor-driven paddle wheel; suitable for ponds up to a few acres and can be sized down for small village ponds (Sunfish Fish Farms, 2026).
- **Solar-powered diffused air pumps:** A solar panel charges a battery that runs a small air compressor connected to diffuser stones; well suited to shallow ponds, nursery tanks and bore-well-fed ponds, and can run on a timer during the low-DO pre-dawn hours (Solar Aeration Systems, 2026).
- **Passive solar (thermally driven) aerators:** A design developed at the University of Toronto uses solar heating of an updraft column to circulate pond water without any electricity or moving parts, mixing the oxygen-rich surface layer with deeper water (Zewde, 2017).
- **Wind-assisted aerators:** Windmill-driven paddle wheels or air pumps, useful as a low-cost option in open, wind-exposed rural ponds and can be combined with solar for hybrid operation.
- **Biological/agronomic aeration support:** Maintaining a healthy phytoplankton bloom, avoiding overstocking, liming, and periodic partial water exchange reduce the oxygen demand a pond places on itself, complementing any mechanical or solar aeration that is installed.



Because solar units run on DC power stored in a battery, they can be built in a wide range of capacities, from a small 10-15 W battery-backed air pump adequate for a backyard or nursery pond, up to a 1-3 HP solar paddle-wheel unit for a one- to two-acre grow-out pond. This scalability is what makes solar aeration equally relevant to a large intensive farm looking to cut its electricity bill and to a small extensive carp pond that has never had any aeration at all.

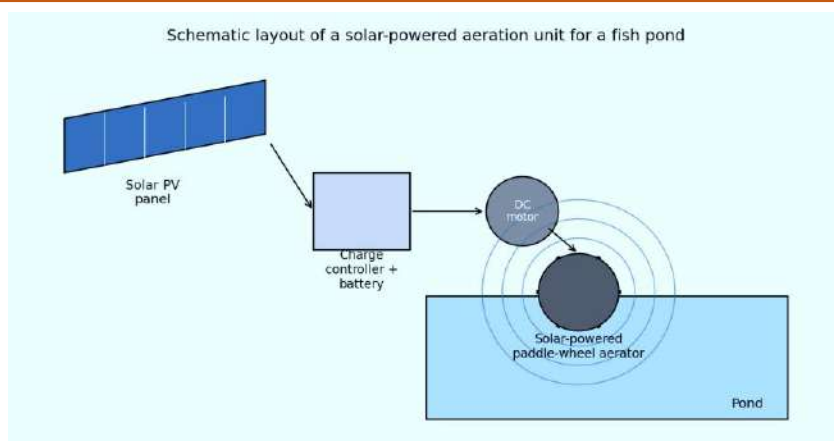


Figure 5. Schematic layout of a solar-powered paddle-wheel aeration unit

Rain-fed and bore-well-fed village ponds share three features that make solar aeration a particularly good fit: they are usually located away from a reliable three-phase grid connection, they are operated on tight margins that cannot absorb a large recurring diesel or electricity bill, and they receive good sunshine for most of the culture season in the plains and peninsular regions of India. A solar aerator removes the dependence on grid power entirely, has a near-zero running cost once installed, and requires only periodic cleaning of the panel and battery maintenance. For carp and carp-tilapia-pacu polyculture ponds, even running the unit for a few hours around dawn, the period of lowest DO, can prevent the periodic mortality events that presently discourage farmers from intensifying these low-input systems. Government schemes such as the Pradhan Mantri Matsya Sampada Yojana (PMMSY) already list aeration and oxygenation equipment, including solar-powered systems, among the beneficiary-oriented components eligible for capital subsidy, which further improves the economic case for small farmers to adopt solar aeration (Department of Fisheries, GoI, 2026; PIB, 2020).

Emerging and High-Efficiency Aeration Technologies

Beyond the paddle-wheel, aspirator and diffused-air units described above, a new generation of higher-efficiency and sensor-driven aeration technologies is now moving from research trials into commercial ponds, and several of these are a natural fit with a solar power source:

- **Nanobubble and micro-bubble aeration:** Generators that produce billions of sub-micron gas bubbles per millilitre give oxygen transfer efficiencies of roughly 85-90%, several times higher than conventional paddle-wheel or diffused-air aeration, because the bubbles stay suspended in the water column for hours rather than rising and bursting at the surface within seconds. Trials on shrimp raceways have reported markedly higher dissolved-



oxygen levels, growth and yield compared with standard diffuser aeration, alongside a reduction in surface biofilms and pathogen load (FAO, 2023; The Fish Site, 2021; Moleaer, 2026).

- **IoT-enabled, sensor-based smart aeration:** Low-cost dissolved-oxygen, pH and temperature sensors linked to a microcontroller (commonly an ESP32-type board) and a solar-charged battery allow an aerator to switch on automatically once DO falls below a set threshold, rather than running on a fixed timer. Data can be pushed to a mobile app or cloud dashboard so the farmer is alerted before a crash occurs. Pilot systems combining solar power with real-time IoT monitoring and automated aeration control have shown they can restore dissolved-oxygen levels faster than manually operated units while cutting the hours the aerator needs to run (Novianarenti, 2026).
- **Floating solar-aeration platforms:** Floating photovoltaic arrays mounted directly on the pond surface can power an aerator while simultaneously shading part of the water, which moderates temperature swings and can help suppress excessive algal growth, making this a dual-purpose option for larger semi-intensive and intensive ponds (8MSolar, 2026).
- **Hybrid solar-wind-battery systems:** Pairing solar panels with a small wind generator and a battery bank gives more continuous aeration through cloudy, low-sun spells than a solar-only unit, and is increasingly offered as a packaged system for farms that cannot risk any gap in aeration during the critical pre-dawn hours (8MSolar, 2026).

Nanobubble generators and IoT-based smart controllers still carry a higher upfront cost than a basic paddle wheel, which currently limits their use to larger commercial or export-oriented farms. However, as component costs fall and more manufacturers enter the market, solar-powered and sensor-controlled aeration is becoming progressively more accessible, and is likely to filter down to semi-intensive carp and carp-tilapia-pacu ponds over the coming years in the same way solar paddle-wheel units already have.

Economic and Environmental Benefits of Solar Aeration

Economic benefits

- Near-zero recurring fuel or electricity cost after the initial investment, since the sun is a free energy source.
- Lower long-term cost per hour of operation compared with diesel gensets, whose fuel cost keeps rising every season.



- Reduced risk of catastrophic crop loss from oxygen-depletion mortality, protecting farm income.
- Potential to safely raise stocking density in extensive and semi-intensive ponds, improving yield per unit area.
- Eligibility for capital subsidy under central and state fisheries schemes, which lowers the effective purchase price for small and marginal farmers.

Environmental benefits

- Displaces diesel combustion, cutting greenhouse-gas emissions and local air pollution associated with genset use.
- Silent operation compared with diesel gensets, reducing noise disturbance in rural residential areas.
- Improves water-column oxygenation and reduces bottom sludge build-up, supporting a healthier pond ecosystem and reducing the release of methane and hydrogen sulphide from anaerobic sediments.
- Uses a renewable, non-depleting energy source and avoids the risk of fuel or oil spillage into the pond that is associated with genset-based systems.

Conclusion

Aeration is a well-recognised tool for maintaining dissolved oxygen and preventing mortality in fish ponds, but its use so far has been concentrated in intensive and commercial semi-intensive farms that can absorb the running cost of grid or diesel-powered aerators. The much larger population of extensive and low-input semi-intensive village ponds, mostly carp or carp-tilapia-pacu polyculture systems fed by rainfall or bore-wells, has largely gone without aeration. Solar aeration, scalable from a small battery-backed diffuser to a full solar paddle-wheel unit, offers a practical, low-running-cost and environmentally cleaner way to close this gap, and its inclusion under existing fisheries subsidy schemes makes it an increasingly realistic option for small and marginal farmers to adopt across extensive, semi-intensive and intensive systems alike.

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Weather Forecasting: Methods for Better Farm Outcomes and Effective Livestock Management

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Introduction

Weather is one of the most significant factors influencing livestock management. Livestock management has become increasingly difficult in recent years due to increased climate variability. Animal health, growth and development, reproduction, milk production, and farm profitability are directly affected by temperature, humidity, rainfall, wind speed, and solar radiation. For effective management, livestock farmers therefore require rapid and reliable weather data. Therefore, weather forecasting is a valuable tool that helps livestock farmers make informed decisions.

WEATHER FORECASTING: A MODERN TOOL FOR DECISION-MAKING

Weather forecasting is the scientific process of predicting future atmospheric conditions, such as temperature, humidity, wind, and precipitation, at a particular area.

Weather forecast types that are helpful for managing livestock include:

- Nowcast (0 - 6hrs): This is a forecast of the weather for a very brief time frame.
- Short-range forecast (1 to 3 days): It offers details on wind speed, humidity, rainfall, and temperature. This aids in scheduling livestock grazing, shielding animals from intense rain or storms, and modifying feeding and watering schedules.
- Medium-range forecast (4 to 10 days): It offers weather information for the coming weeks. This information is useful for planning immunization and deworming regimens, as well as for harvesting and storing feed.



- Long-range forecast (>30 days): Also known as a seasonal forecast, it predicts seasonal patterns such as temperature trends, monsoon performance, and drought conditions.

WEATHER FORECAST: HOW CAN FARMERS GET IT?

Farmers can access weather information through the official websites of the India Meteorological Department (IMD), agricultural extension services, Krishi Vigyan Kendras (KVKs), on-farm sensors, private weather applications such as AccuWeather and The Weather Channel, and mobile apps like Meghdoot and Mausam app

The India Meteorological Department (IMD) launched the Gramin Krishi Mausam Seva (GKMS) agro-meteorological program to give farmers localized crop recommendations and precise weather forecasts. It reduces crop hazards and increases agricultural yields by working with State Agricultural Universities, such as KAU in Kerala. Its main goal is to provide farmers with location-specific, weather-based agromet alerts so they may reduce weather risks, maximize resource use, and increase crop and livestock yield.

Agrometeorological warnings and location-specific weather forecasts are provided to farmers by the GKMS. This aids farmers in controlling disease outbreaks, protecting livestock from harsh weather, and providing the best possible food and shelter.

WEATHER'S IMPACT ON DISEASE OUTBREAKS AND LIVESTOCK PESTS:

Sl. No.	DISEASES	FAVORABLE WEATHER CONDITIONS	MANAGEMENT
CATTLE			
1.	Foot and mouth disease 	The virus thrives in cool, moist, and extremely humid conditions.	FMD has no effective treatment; therefore, vaccination and strict biosecurity measures are essential.



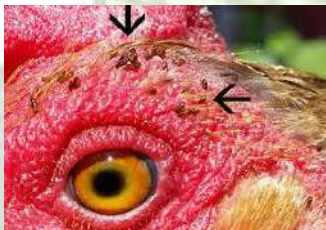
2.	Actinobacillosis (Wooden Tongue) 	Most severe and common during dry, drought-like circumstances or right after significant flooding	A healthy diet, keeping sick animals apart, and disinfection
3.	Heat stress 	Hot and humid weather conditions.	Provide water and shade, and refrain from overworking livestock in the summer.
4.	Anthrax 	Most severe during periods of intense rainfall or flooding that are followed by a hot, dry summer.	Early cases may benefit from vaccination and high doses of penicillin administered under veterinary supervision.
POULTRY			
1.	Ranikhet 	Severe in the spring and winter. The virus can live in cool, humid weather	Sanitation, disinfection, immunization, biosecurity, and quarantine



2.	Bird-flu 	cold and dry weather conditions.	Maintain proper Hygiene, quarantine, minimize contact with wild birds, proper disposal of carcasses, disinfection
3.	Marek's disease 	Severe during colder, darker and in winter months	Maintain proper hygiene, all-in/ all-out protection, resistant strain (B21 GENE), vaccination

Sl. No.	PEST	FAVOURABLE WEATHER CONDITION	MANAGEMENT
CATTLE			
1.	Horn flies/ buffalo fly <i>(Haematobia irritans)</i> 	During very hot or rainy weather flies move to the underside of the belly to feed on blood meal.	To avoid pesticide resistance, use different chemical classes (such as synthetic pyrethroids and organophosphates). Get rid of the



			maggots in the excrement.
2.	Cattle grub (<i>Hypoderma spp.</i>) 	Grub requires warm, sunny, and dry weather, with temperatures consistently between 15° C and 26° C.	Systemic insecticides: Cydectin pour-on (moxidectin) 30–60 days after fly activity has ceased
POULTRY			
1.	Sucking Lice (<i>Haemetopinus eurysternus</i>) 	In warm, humid weather, pest attacks will be more severe.	Spray or dip the bird in 5% dust or 0.5% suspension, or apply linseed oil all over its body.
2.	Mite 	When temperatures are between 20°C and 25°C and relative humidity is more than 70%, infestation is more severe.	Use of acaricides such as Exzolt-R, Organophosphate phoxim, and Fluralaner-based products

Source: Cattle Diseases: The Farmers' Guide, Department of Primary Industries and Regions South Australia (PIRSA).



Climate change's effects on livestock production



Direct impacts:

1. Metabolic problems, decreased reproduction, and decreased milk production are caused by heat and cold stress.
2. Illnesses that cause death



Indirect impacts:

1. Water scarcity
2. Variations in feed quantity and quality
3. The rise in pest populations and the emergence of new diseases

WEATHER FORECAST APPLICATIONS IN LIVESTOCK MANAGEMENT:

Livestock farmers can make quick decisions to protect animals and increase productivity with the aid of weather predictions. These applications include:



1. Protecting animals from the heat, as heat stress reduces growth and milk production. Therefore, during hot weather, farmers can use prediction information to offer drinking water, shade, and a cooling system at the shed.
2. Protection in cold weather: The health of young and frail animals can be impacted by cold weather. Additionally, cold stress raises mortality and morbidity (Mader, 2003). Therefore, producers can use the knowledge to set up shelters and additional feed during cold weather.
3. Rainfall forecasts assist farmers in organizing the production, harvesting, and storage of fodder.
4. Disease Prevention: Pasture availability and the disease cycle are influenced by temperature and rainfall (Lamy et al., 2012). This aids farmers in taking preventive actions like immunization, sanitation and pest control (horn flies and tick infestations are more common in hot, dry weather, mosquitoes and liver fluke infestations are more common in warm, rainy weather, and bovine lice infestations usually peak in late winter).
5. Use water efficiently and conserve it during dry spells.
6. Early warnings of floods, cyclones, droughts, and storms allow farmers to prepare feed, water, medicines, and shelter in advance.
7. Grazing activity: Low rainfall and high temperatures deteriorate pasturelands and reduce feed conversion rates (Rowlinson, 2008). Predictive information aids in choosing appropriate grazing periods and preventing severe weather.

ENHANCING FARM OUTCOMES THROUGH LIVESTOCK MANAGEMENT AND CLIMATE-SMART AGRICULTURE:

Better resource management, increased farm productivity, and increased resilience to climate variability are all supported by incorporating weather forecasting into climate-smart agriculture and livestock management techniques.

Strategies for adaptation:

1. Fodder conservation through the production of silage or hay.
2. Growing forages that can withstand drought, such as tall fescue, cowpeas, alfalfa, pearl millet, and sorghum



3. Better dwelling design through the use of cooling systems and naturally ventilated or shaded buildings.
4. Effective water management through adequate irrigation for fodder crops and rainfall collection for animals.

CONCLUSION:

Weather forecasting is a crucial decision-support tool for managing climatic variability and maintaining farm profitability because weather strongly influences animal health, milk production, and disease cycles. Farmers can proactively modify grazing, plan vaccination schedules, and get ready for seasonal droughts by using short-, medium-, and long-range forecast data from platforms such as the Gramin Krishi Mausam Seva (GKMS). In the end, incorporating these findings into climate-smart strategies guarantees long-term agricultural resilience, maximizes resources, and shields animals from severe stress.





Targeted Yield Approach in Paddy: A Scientific Tool for Balanced Fertilization under Khet Bachao Abhiyan

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Introduction

Targeted yield concept is based on quantitative idea of the fertilizer needs based on yield and nutrient requirements of the crop, per cent contribution of the soil available nutrients and that of the applied fertilizers. This method not only estimates soil test-based fertilizer dose but also determines the level of yield the farmer can achieve with that particular dose. Unlike blanket recommendations, Targeted Yield Approach gives accurate fertilizer dose to apply in the crops. Targeted yield approach also provides scientific basis for balanced fertilization of crop by creating the balance among the nutrients from the external sources and that from the soil.

India's Khet Bachao Abhiyan, 2026 calls for "more crop per drop and per kg of fertilizer." Yet NPK use ratio in Assam stands at 7.8:2.3:1 against ideal 4:2:1, leading to soil fatigue and rising subsidy burden. The Targeted Yield Approach, developed through ICAR's STCR project bridges this gap by linking fertilizer dose to yield target and soil test value.

From three years of research at Assam Agricultural University, Jorhat and verification in seven numbers of farmers field fertilizer prescription equations for targeted yield of autumn rice were developed (Table 1) and based on this a ready reckoner was prepared for a range of soil test values for yield target of 40 q ha⁻¹ under NPK alone and NPK + FYM (Table 2)

Table 1: Soil test based fertilizer prescription equations for autumn rice

Particulars	NPK alone	NPK with FYM
FN	5.30T-0.27SN	5.30T-0.27SN-0.72 ON



F P ₂ O ₅	2.94T-0.47SP ₂ O ₅	2.94T-0.47SP ₂ O ₅ -0.41OP
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F K ₂ O	4.72 T-0.46SK ₂ O	4.72T-0.46SK ₂ O-0.62OK
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Where,

T= Targeted Yield, S= Soil, O= Organic manure

Table 2: Ready reckoner for yield target of 40 q ha⁻¹ under NPK + FYM.

Initial status	Target yield (40 q ha ⁻¹)		
N: P ₂ O ₅ : K ₂ O	NPK alone	NPK+5 tonne FYM ha ⁻¹	NPK+10 tonne FYM ha ⁻¹
200: 10: 120	158: 113: 134	140: 109: 118	122: 105: 103
250: 15: 125	144: 110: 131	126: 106: 115	108: 101: 100
300: 20: 130	131: 108: 129	113: 104: 113	95: 99: 98
350: 25: 135	117: 106: 127	99: 102: 111	81: 98: 96

If the soil available nutrients is 200, 10 and 120 kg ha⁻¹ of N, P₂O₅ and K₂O, then to attain a yield target of 40 q ha⁻¹ recommended fertilizer dose will be 158, 113 and 134 kg ha⁻¹ of N, P₂O₅ and K₂O under NPK alone and 140, 109 and 118 kg ha⁻¹ of N, P₂O₅ and K₂O under NPK + 5 tonne FYM ha⁻¹. If 10 tonne FYM ha⁻¹ is applied along with chemical fertilizer, then the recommended dose will be 122, 105 and 103 kg ha⁻¹ of N, P₂O₅ and K₂O. Application of FYM along with soil test based fertilizer recommendation (300: 20: 130) would save 18, 4 and 16 kg ha⁻¹ of N, P₂O₅ and K₂O at 5 t ha⁻¹ and 36, 8 and 31 kg ha⁻¹ of N, P₂O₅ and K₂O at 10 t ha⁻¹.

Case example: Every season, Lakhi Kalita of Barpeta district bought 4 bags of urea for his 2 bigha paddy field because everyone does it. Last year his yield dropped to 12 quintals. Soil test at KVK Barpeta showed his field was already high in nitrogen and phosphorus and low in potassium. Using the Targeted Yield Approach, KVK gave him a Soil Health Card suggesting application of 30 kg less urea, increase in the application of MOP by 10 kg for a 20 quintal target. Result? He saved Rs 800 and harvested 18 quintals of paddy. This is the power of balanced fertilization – giving soil only what it needs for the yield you want.

Farmers quote: “Earlier I used 2 bags DAP blindly. After Targeted Yield Approach, 1.5 bags gave me 3 quintal more”- Ramen Das, Sarupeta.

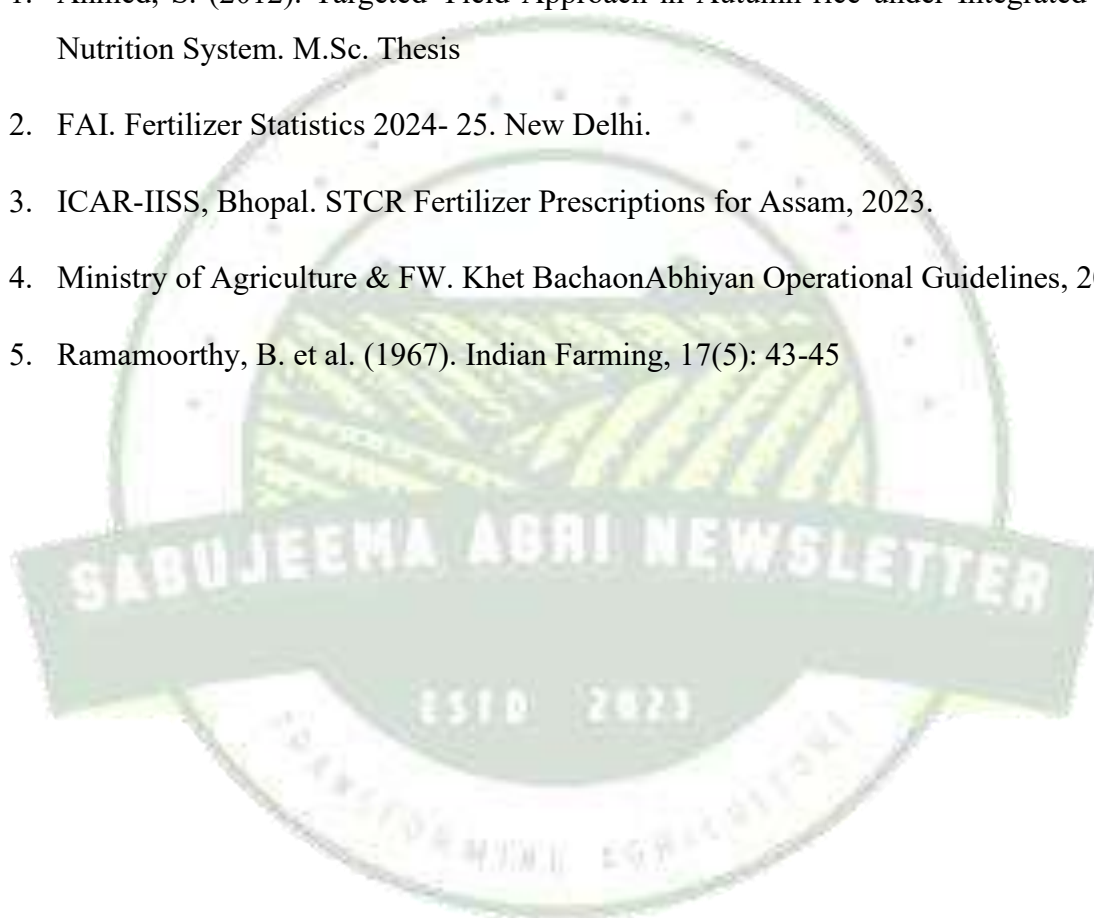


Targeted Yield Approach is not a new scheme to implement. It is a decision tool to make existing soil Health Card and fertilizer subsidy schemes more precise. Recommending Targeted Yield Approach ensures – lower cost of production, higher yield and long term soil health.

Let us move from 'fertilizer application' to 'nutrient management' – one field, one target at a time.

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Entomopathogenic Fungi as Sustainable Alternatives to Synthetic Insecticides in Pulse Ecosystems

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Introduction

Pulse crops, play a pivotal role in sustainable agriculture due to their nutritional importance and ecological benefits. As rich sources of plant-based protein, they contribute significantly to food and nutritional security, particularly in developing countries. In addition, their ability to fix atmospheric nitrogen through symbiotic associations with rhizobia enhances soil fertility, reduces dependence on synthetic fertilizers and supports environmentally sustainable cropping systems. Despite their agricultural significance, pulse production is frequently constrained by a diverse complex of insect pests such as pod borers, armyworms, aphids and whiteflies. Among these, the gram pod borer, *Helicoverpa armigera* (Hübner), is regarded as one of the most damaging pests owing to its polyphagous nature, high reproductive potential and capacity to attack crops at multiple growth stages. Infestations by this pest can result in substantial economic losses with yield reductions commonly ranging from 30 to 57%, and under severe outbreaks occurring at critical crop growth stages, losses may approach complete crop failure (Singla and Singh, 2020).

For many years, synthetic insecticides have been relied upon as the primary means of controlling insect pests in pulse crops. Although these products provide rapid pest suppression, their repeated use has created several challenges, including the development of insecticide resistance, resurgence of pest populations, contamination of soil and water resources and adverse effects on beneficial insects such as pollinators and natural enemies (Ruiu, 2018). Growing concerns about environmental sustainability and food safety have therefore encouraged researchers and farmers to explore alternative pest management strategies that are both effective and environmentally responsible.



Challenges of synthetic insecticides in pulse production

The widespread dependence on chemical insecticides has undoubtedly contributed to increased crop productivity. However, continuous exposure of insect populations to the same active ingredients has accelerated the evolution of resistance in several economically important pests. *Helicoverpa armigera*, for example, has developed resistance to multiple classes of insecticides across many agricultural regions worldwide (Fitt, 1989).

In addition to resistance, synthetic insecticides can negatively affect non-target organisms that contribute to ecosystem stability. Beneficial arthropods such as ladybird beetles, lacewings, parasitoids and pollinators are often exposed to pesticide residues, reducing their abundance and effectiveness in natural pest regulation. Furthermore, excessive chemical inputs may lead to environmental contamination and raise concerns regarding human health and food quality.

Entomopathogenic fungi as nature's insect killers

Entomopathogenic fungi (EPF) are naturally occurring microorganisms capable of infecting and killing insects. Unlike bacterial and viral pathogens that usually require ingestion by the host, EPF can infect insects directly through their external body surface. This unique characteristic makes them highly valuable biological control agents against a broad spectrum of agricultural pests.

Several fungal species have been successfully developed as microbial biopesticides. Among them, *Beauveria bassiana*, *Metarhizium anisopliae*, *Lecanicillium lecanii* and *Isaria fumosorosea* are widely recognized for their effectiveness against numerous insect pests affecting agricultural crops. These fungi naturally occur in soils and agricultural habitats, where they play an important role in regulating insect populations.

How Entomopathogenic Fungi Infect Insects

The infection process begins when fungal spores come into contact with the insect cuticle. Under suitable environmental conditions, the spores germinate and produce specialized structures that penetrate the insect's outer protective layer. Once inside the body cavity, the fungus proliferates rapidly, utilizing host nutrients and producing toxins that disrupt physiological functions. Eventually, the infected insect dies, after which the fungus emerges from the cadaver and produces new spores capable of infecting additional hosts (Kavya et al., 2025).



This mode of action differs significantly from that of conventional insecticides and provides an important advantage in resistance management. Since EPF attack insects through multiple physiological pathways, the likelihood of rapid resistance development is considerably reduced.

Role of Entomopathogenic Fungi in Pulse Pest Management

Research conducted across different pulse-growing regions has demonstrated the effectiveness of EPF against several major insect pests. *Beauveria bassiana* has shown promising activity against *Helicoverpa armigera*, *Spodoptera litura*, aphids and whiteflies. Similarly, *Metarhizium anisopliae* has been successfully used against soil-dwelling and foliar-feeding insect pests.

Apart from directly suppressing pest populations, EPF contribute to the conservation of beneficial organisms because of their relatively high target specificity. Recent studies have also revealed that some entomopathogenic fungi can colonize plant tissues as endophytes. Such associations may enhance plant growth, improve tolerance to environmental stresses, and increase resistance against insect attack, thereby providing additional benefits beyond pest control (Vega, 2018).

Advantages of EPF in Sustainable Agriculture

The increasing popularity of entomopathogenic fungi is largely attributed to their compatibility with sustainable agricultural practices. Unlike many synthetic insecticides, EPF leave minimal harmful residues in the environment and generally pose lower risks to humans, livestock and beneficial insects. Their integration into Integrated Pest Management (IPM) programmes helps reduce dependence on chemical pesticides while maintaining effective pest suppression.

Another significant advantage is their compatibility with organic farming systems. Since EPF are naturally occurring organisms, they align well with consumer demands for safer and more environmentally friendly food production. Their use also supports biodiversity conservation by preserving beneficial insect communities that contribute to ecosystem services.

Constraints and Future Prospects

Despite their numerous advantages, several challenges limit the large-scale adoption of entomopathogenic fungi. Environmental factors such as temperature, humidity and ultraviolet radiation can influence fungal survival and effectiveness under field conditions. In some



situations, EPF may act more slowly than conventional insecticides, requiring careful timing of application.

Recent advances in formulation technology, strain improvement and microbial biotechnology are helping overcome these limitations. The development of oil-based formulations, microencapsulation techniques and nano-enabled delivery systems has improved fungal persistence and field performance. Furthermore, integration of EPF with botanicals, semiochemicals and precision agriculture tools offers new opportunities for sustainable pest management.

Conclusion

The future of pulse production depends on the adoption of pest management strategies that balance productivity with environmental stewardship. Entomopathogenic fungi represent one of the most promising biological alternatives to synthetic insecticides due to their unique mode of action, environmental compatibility and effectiveness against a wide range of insect pests. Their integration into pulse-based farming systems can reduce chemical dependency, conserve beneficial organisms and contribute to long-term agricultural sustainability. As research and formulation technologies continue to advance, EPF are likely to play an increasingly important role in the development of resilient and eco-friendly crop protection programmes.

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Climate-Smart Farming: Reimagining Food Production for a Warming World

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Introduction

Every monsoon now arrives a little differently than the one before it. Farmers across India, and indeed across the world, have noticed it for years before scientists put numbers to it: the rains come late, or too much at once, or not at all in the months when crops need them most. Summers stretch longer and hotter, winters shrink, and pests that once stayed confined to certain seasons now show up whenever they please. Agriculture, the activity most directly exposed to the sky, is also the one most directly exposed to a changing climate. And yet, agriculture is not merely a victim of this change — it is also one of its contributors, and more importantly, one of its most promising solutions.

This is the central idea behind climate-smart agriculture, an approach that does not treat “growing more food” and “protecting the environment” as competing goals, but as two halves of the same task. The concept rests on three pillars: increasing agricultural productivity and farmer incomes sustainably, building resilience and adaptive capacity in farming systems, and reducing or removing greenhouse gas emissions wherever possible. None of these pillars works well alone. A farm that produces more food but collapses under the next drought has not solved anything. A farm that conserves water beautifully but cannot feed the family that depends on it has also failed. Climate-smart food systems try to hold all three goals in balance.

Reading the Soil Before Reading the Sky

One of the quieter revolutions in climate-smart agriculture is happening below the surface, in the soil itself. Healthy soil, rich in organic carbon and biological life, behaves like a sponge: it absorbs water during heavy rain and releases it slowly during dry spells, cushioning crops against both extremes. Practices such as minimum tillage, cover cropping, crop residue retention, and the judicious use of organic manures rebuild this sponge-like quality over a few seasons. Conventional intensive tillage, by contrast, exposes soil organic matter to oxidation,



releases stored carbon back into the atmosphere, and leaves the land more vulnerable to erosion and moisture loss. The shift toward conservation agriculture, therefore, is not just an environmental nicety — it is a direct investment in a farm's ability to survive an unpredictable season.

Water: The Resource That Decides Everything

If soil is the foundation, water is the variable that decides whether a season succeeds or fails. Climate-smart water management does not mean using less water for its own sake; it means using water at the right time, in the right amount, through the right method. Micro-irrigation systems such as drip and sprinkler irrigation can cut water use substantially compared to flood irrigation while often improving yields, because water and nutrients are delivered directly to the root zone rather than lost to evaporation or runoff. Rainwater harvesting structures, farm ponds, and the revival of traditional water-storage systems extend the usable water window well beyond the monsoon. Equally important is choosing crop varieties and cropping calendars that match the water actually available, rather than the water a farmer hopes will arrive.

Crops and Varieties Built for Uncertainty

Plant breeding has not stood still in the face of climate change. Research institutions have released numerous stress-tolerant varieties — rice that survives submergence for over a week, wheat that tolerates a few extra degrees during grain filling, and pulses bred to flower earlier so they escape terminal heat. Equally valuable is the renewed interest in millets and other traditionally hardy crops, which require far less water than rice or wheat and tolerate poor soils and erratic rainfall with relative ease. Diversifying what is grown, rather than depending on one or two staple crops, spreads risk across a farm the way a varied investment portfolio spreads financial risk. When one crop fails due to an unexpected weather event, others planted alongside it may still deliver a harvest.

Information as a Farming Input

Perhaps the most underrated climate-smart tool is not a seed or a sprinkler but a piece of timely information. Weather advisories delivered through mobile applications, agromet bulletins, and community radio now allow farmers to make decisions — when to sow, when to spray, when to irrigate — based on short-term forecasts rather than guesswork or memory of past years. Decision-support tools that combine soil data, weather forecasts, and crop models can tell a farmer the precise nitrogen requirement of a field on a given day, reducing both costs and



excess fertilizer runoff into water bodies. As mobile connectivity expands into rural areas, this kind of precision is becoming available not only to large commercial farms but to smallholders cultivating just one or two acres.

The Human Side of a Climate-Smart Transition

Technology and agronomy aside, the success of climate-smart food systems ultimately depends on people — on whether a smallholder farmer trusts a new practice enough to risk a season on it, and whether the support systems around that farmer make the transition affordable. Government schemes that subsidize micro-irrigation equipment, insurance products that cushion the financial blow of a failed harvest, and farmer-producer organizations that pool knowledge and bargaining power all matter as much as the science itself. Extension workers and agricultural universities have a particularly important role to play in translating research findings into field-level practice, often through demonstration plots where farmers can see a climate-resilient method working on land similar to their own before adopting it themselves.

A Shared Responsibility, A Shared Opportunity

Climate-smart agriculture is sometimes presented as a burden — one more set of standards that farmers, already squeezed by rising costs and uncertain markets, must somehow meet. A more accurate framing is that it is an opportunity hiding inside a constraint. Soils that store more carbon are also more fertile. Crops bred for stress tolerance are also more reliable income sources. Water saved through efficient irrigation is also money saved on diesel or electricity for pumping. The same set of practices that helps the planet also, in most cases, helps the farmer's own balance sheet.

The path to climate-resilient food systems will not be built by any single technology or policy. It will be built, field by field, through the accumulated choices of millions of farmers, supported by researchers who keep refining what works, policymakers who make the right practices affordable, and consumers who increasingly value food grown with the planet in mind. The monsoon may keep arriving differently each year, but with the right knowledge and tools in hand, agriculture can learn to meet it on its own terms.

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Preliminary analysis of genetic diversity among cowpea genotypes by using ISSR markers

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Abstract

Cowpea, *Vigna unguiculata* (L.) Walps ($2n = 2x = 22$), is an important food legume consumed across the world as a major source of carbohydrates and proteins. The plant possesses diverse characteristics at genetic level henceforth for the morphology as well. Molecular investigations in *Vigna unguiculata* (cowpea) have significantly advanced the understanding of its genetic architecture, diversity, and trait inheritance. Various DNA-based markers have been extensively utilized to characterize genetic variability among cultivated and wild accessions, revealing substantial genetic diversity and distinct population structures over the traditional approach. The efforts were taken to study genetic diversity among locally adapted and recommended cowpea genotypes by Mahatma Phule Krishi Vidyapeeth Rahuri using ISSR markers. Study revealed that ISSR markers can distinguish among closely related genotypes with high precision. Among four ISSR primers analyzed subset showed significant polymorphism, revealing their potential as powerful tools for genetic diversity.

Keywords: Cowpea, ISSR, genetic diversity, polymorphism

Introduction:

Cowpea, *Vigna unguiculata* (L.) Walps ($2n = 2x = 22$), is an important food legume in developing countries of the tropics and subtropics, especially in sub-Saharan Africa, Asia, and Central and South America and in some temperate areas, including the Mediterranean region



and the southern states of the USA. Cowpea is a very important source of carbohydrates (63%) and proteins (25%), with low fat content (1.5%) and is rich in minerals (Ca, P, Fe) and vitamins folate, thiamine, and riboflavin. It has natural tolerance to biotic and abiotic stress to grow in poor soil due to its high ability for nitrogen fixation. It is used as vegetable crop and green or dry fodder is also used as green manure. The plant possesses wide intra species diversity for various characteristics such as plant type, growth habit, terminal leaflet shape, flower color and its characteristics, pod type and shape, and seed type and shape and its Testa color and texture (Bisht *et al.*; 2005). Despite, there are a very big lack of germplasm which can utilize for improvement and breeding programme.

Globally in 2023-24, the crop was grown on nearly 15 million hectares, with an estimated global production of around 9 to 10 million tonnes (Olorunwa *et al.*, 2023; Laosatit *et al.*, 2024). The average productivity is about 600–650 kilograms per hectare, though this varies significantly by country. In India, annual production of cowpea is around 2.5 lakh tonnes cultivated over an area of approximately 4.0 lakh hectares (Murthy *et al.*, 2025). Overall, the global trend shows gradual increases in both production and productivity, but yields remain low compared to the crop's potential. Traditional, research-backed approaches to raise cowpea (*Vigna unguiculata*) production combine varietal improvement with agronomic and crop-management practices: deploying high-yielding, locally adapted and pest-resistant cultivars developed through breeding programs.

Molecular investigations in *Vigna unguiculata* (cowpea) have significantly advanced the understanding of its genetic architecture, diversity, and trait inheritance. Various DNA-based markers, including ISSR, SSR, RAPD, AFLP, and SNPs, have been extensively utilized to characterize genetic variability among cultivated and wild accessions, revealing substantial polymorphism and distinct population structures (Vaishna *et al.*; 2026). Molecular marker analysis have facilitated the identification of quantitative trait loci (QTLs) and candidate genes associated with key agronomic traits such as drought tolerance, disease resistance, seed quality, and yield stability. Furthermore, transcriptomic and genome-wide association studies (GWAS) have elucidated differential gene expression patterns under abiotic stresses and provided insights into the molecular mechanisms governing symbiotic nitrogen fixation (Boukar *et al.*, 2018) The recent availability of the cowpea reference genome has enabled the development of high-density SNP arrays and the application of marker-assisted selection (MAS) and genomic selection (GS) in breeding programs. Collectively, these molecular studies contribute to accelerating genetic improvement, germplasm conservation, and sustainable production of



cowpea under diverse agro-ecological conditions. In the present study, efforts were taken to study genetic diversity among locally adapted and recommended cowpea genotypes by Mahatma Phule Krishi Vidyapeeth Rahuri using ISSR markers.

Material and Methods:

This study was carried out at Vidya Pratishthan's College of Agricultural Biotechnology Baramati, Maharashtra during the year 2025-2026. The materials use and methodology adopted are presented below. In the concerned study the seeds of ten genotypes were collected from Pulses and Oilseed crops research and Training Centre, Pandharpur under Mahatma Phule Krishi Vidyapeeth Rahuri, Maharashtra and sown in the pots at nursery. Salient features of the cowpea genotypes are mentioned in the table no.1. Two gram of fresh cowpea leaf samples were taken from each genotype and wash with distilled water. The leaf sample was crushed by adding liquid nitrogen and followed by adding 3% CTAB buffer into mortar and pestle. The DNA was extracted from the cowpea leaf samples by using modified protocol of Doyle and Doyle (1990). RNase A treatment is used for the removal of RNA from genomic DNA samples. DNA quantification was done with 0.8 % agarose gel electrophoresis (Sambrook *et.al.*, 1989) and UV-Vis Spectrophotometer (Sca drpoop...) . Molecular screening of these samples was done by using four ISSR markers. Primer sequences of ISSR markers are listed out in the table no. 2. PCR reaction was carried out for all ten cowpea genotypes by using Prima-96™ HiMedia Laboratories thermal cycler. Each reaction was carried out with 20 µl reaction volume containing 5 ng of genomic DNA, 10 pmol of primer, 2 mM of dNTPs, 2 mM MgCl₂, 1 X amplification buffer and 1 U of Taq DNA polymerase. The thermal cycling conditions were as follows: 4 min initial denaturation at 94 °C; 35 cycles of 1 min denaturation at 94 °C, 1 min of annealing at 45 °C to 50 °C, 2 min extension at 72 °C; and a final 7 min extension at 72 °C. PCR amplified products were checked on the 2.5 % agarose gel. The amplified profiles for all the primers were compared with each other and band of DNA fragments were scored as '1' for presence and '0' for absence, generating '0' and '1' matrix. Molecular weights of the band were estimated by using 1kb ladder as standards. All amplification were repeated at least twice and only reproducible bands were considered for analysis. Percent polymorphism was calculated (Jaccard *et al.*, 1908). The polymorphic information content (PIC) values calculated for each primer (Rolf *et al.*, 2005). The similarity matrix of Cowpea genotypes based on NTSYS pc UPGMA clustering method similarity coefficient from ISSR marker was done.



Results and Discussion:

Genomic DNA extracted from all ten cowpea genotypes was good at quality and quantity. DNA concentration was in the range of 1034 to 1172 ng/μl with the negligible contamination of protein, RNA and other cell debris. Modified CTAB method was efficient for the isolation of genomic DNA from cowpea leaf tissues. Four ISSR primers were employed to evaluate the genetic diversity among the selected samples. The performance of each primer was assessed based on the total number of bands (NSb), monomorphic bands (NMb), polymorphic bands (NPb), and the percentage of polymorphism, which reflects the effectiveness of each primer in detecting genetic variation. A total of 34 bands were amplified across all primers, out of which 27 were polymorphic, indicating a high overall level of genetic diversity. The percentage of polymorphism ranged from 50% (UBC-826) to 85% (UBC-811). The highest number of bands was generated by primers UBC-806 and UBC-807 (09 bands for each primer), whereas UBC-826 produced the fewest (06 bands) (Table no.3, plate no.1).

The dendrogram represents a hierarchical cluster analysis of ten cowpea genotypes based on their genetic similarities. The x-axis shows the coefficient (likely similarity or correlation), ranging approximately from 0.61 to 0.86. A higher coefficient indicates a closer relationship between varieties. The cowpea varieties are grouped into clusters, where those connected by shorter branches are more like each other. Genotypes such as PMCP-1016 and Phule Pandhari form a close pair, indicating high similarity. Some varieties like DC-19-6 and PMCP-1018 form an isolated cluster, indicating moderate similarity with others (Table no 4, Fig. no. 1).

Inter Simple Sequence Repeat (ISSR) markers were employed in this study to evaluate genetic polymorphism among selected cowpea genotypes. ISSR markers are highly reproducible, multilocus, and informative, making them ideal for genotyping in crops like cowpea. The objective was to identify markers capable of distinguishing among closely related genotypes with high precision and among four ISSR primers analyzed subset showed significant polymorphism, revealing their potential as powerful tools for genetic fingerprinting (Ghalmi *et. al.*, 2010; Soaud *et. al.*, 2021 and Diallo *et. al.*, 2024). Notably, primers such as UBC 806, UBC 807, UBC 811 and UBC 826 demonstrated strong discriminatory ability by generating unique banding patterns across several progeny. The presence of distinct bands among cowpea genotypes suggests underlying genomic variations, possibly due to adaptations, recombination or mutations.



Acknowledgement

Authors are thankful to the Pulses and Oilseed crops research and Training Centre, Pandharpur and All India Co-ordinated Research Project on Pulses and Oilseeds under Mahatma Phule Krishi Vidyapeeth Rahuri, Maharashtra, M.P.K.V., Rahuri for providing seeds of cowpea cultivars for this research study.

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Table No. 1. Salient features of selected cowpea genotypes.

Sr. No.	Genotype	Year of Release	Maturity Period	Special features
1.	Phule Pandhari	2007	65-72 Days	Brown shiny grains, short duration erect growth, pale green leaves
2.	Phule Vitthai	2015	65-72 Days	Off white kidney shape seeds, dark green and medium size leaflets
3.	Phule Rukhmini	2016	75-77 Days	Pearly white kidney shape seeds, dark green leaves
4.	Phule Sonali	2021	70-72 Days	Bolder seeds, creamy colour seeds, intercropping, short duration, suitable for dryland conditions.
5.	PMCP-1016	2016	64-70 Days	seeds are whitish yellow in colour, seeds are large in size, pathogen resistant, drought tolerant.
6.	DC-19-6	-	70-75 Days	Heat tolerant, disease and pest resistance, high nutritional content, environment adaptability
7.	PCP-1402	2018	75-78 Days	Indeterminate, seeds are whitish and moderately large, pathogen resistant
8.	PMCP-1018	-	66-70 Days	White and kidney shaped, seeds are white, high nutritional value, salinity tolerant, heat tolerant.



9.	PMCP-1005	2013	66-70 Days	Seeds are white in colour, resistant to parasitic weeds, disease and pest resistant.
10.	CPB-2201	-	72-75 Days	Brownish colour seeds, high yield variety, bacterial blight resistant, reduce soil erosion.

Table no. 2. List of ISSR primers

Sr No.	Primer Name	Sequence	Annealing Temperature
1	UBC-806	TATATATATATATATAG	50 °C
2.	UBC-807	AGAGAGAGAGAGAGAGT	45 °C
3.	UBC-811	GAGAGAGAGAGAGAGAC	50 °C
4.	UBC-826	ACACACACACACACACC	46 °C

Table no. 3. ISSR primer amplification, % polymorphism and PIC values of cowpea genotypes

Primers	Range (bp)	NSB	NMB	NPB	Polymorphism	PIC value
UBC-806	110-840	09	03	06	66%	0.44
UBC-807	120-750	09	03	06	66%	0.44
UBC-811	130-780	07	01	06	85%	0.56
UBC-826	240-620	06	03	03	50%	0.33

(**NSB**- Number of Scorable Markers ☐ **NMB**- Number of Monomorphic Bands ☐ **NPB**- Number of Polymorphic Bands)

**Table no. 4. Similarity matrix of cowpea genotypes from ISSR Markers**

Varieties	PMCP-1016	Phule Pandhara ri	CPB-2201	PCP-1402	DC-19-6	PMCP-1018	Phule Vitthai	Phule Rakhumai	Phule Sonali	PM CP-1005
PMCP-1016	1.00									
Phule Pandhara ri	0.862	1.00								
CPB-2201	0.724	0.741	1.00							
PCP-1402	0.580	0.656	0.814	1.00						
DC-19-6	0.629	0.655	0.629	0.592	1.00					
PMCP-1018	0.600	0.517	0.481	0.444	0.619	1.00				
Phule Vitthai	0.666	0.580	0.666	0.629	0.560	0.750	1.00			
Phule Rakhumai	0.807	0.700	0.678	0.703	0.708	0.691	0.750	1.00		
Phule Sonali	0.535	0.468	0.535	0.555	0.541	0.736	0.805	0.666	1.00	
PMCP-1005	0.730	0.630	0.666	0.629	0.695	0.750	0.818	0.826	0.852	1.00

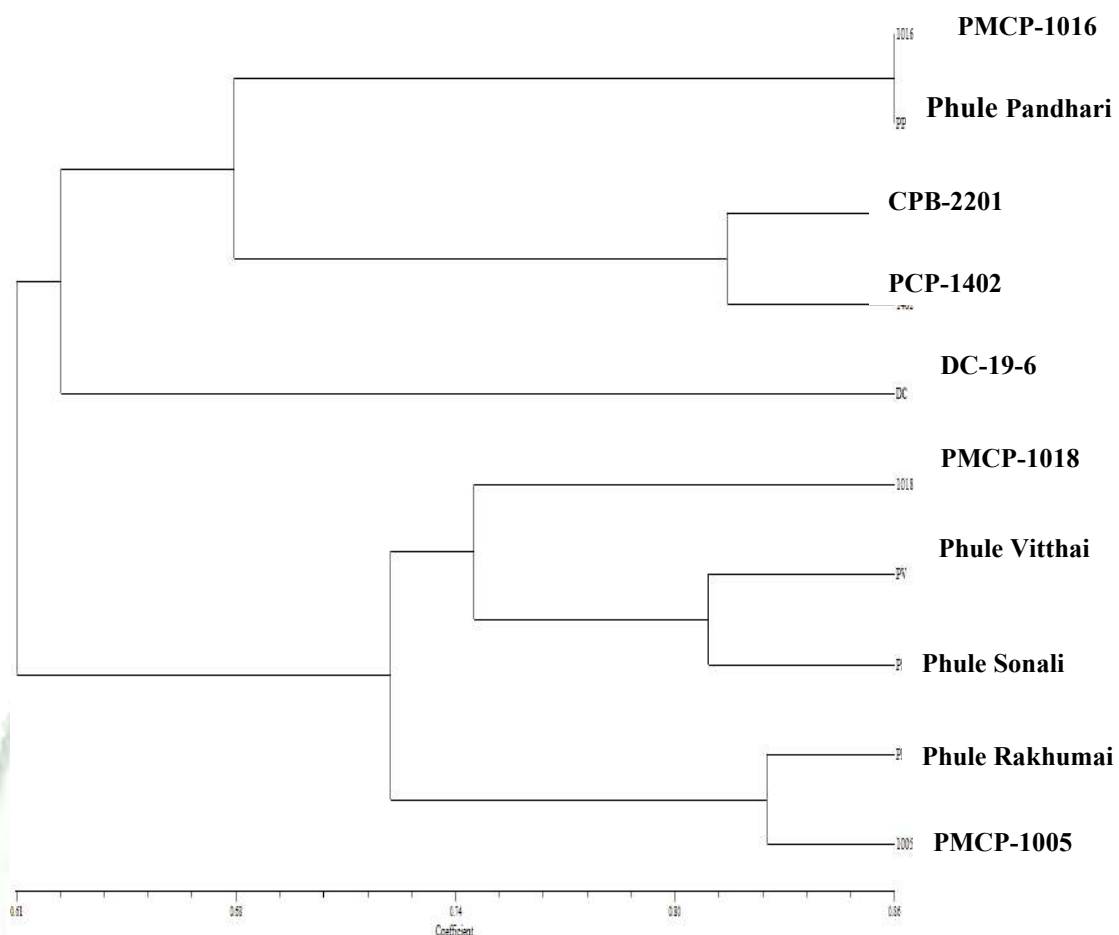


Fig. no.1. Dendrogram generated among cowpea genotypes by UPGMA analysis based on ISSR markers



L 1 2 3 4 5 6 7 8 9 10

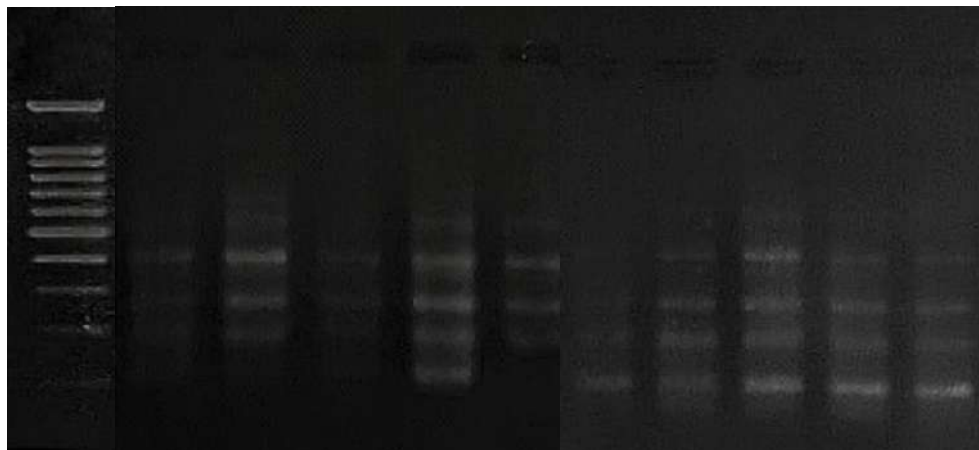


Plate No.1. ISSR Profiles of cowpea genotypes obtained with UBC-807 Primer L-1Kb, 1.PMCP-1016, 2. P. Pandhari, 3. CPB-2201, 4. PCP-1402, 5. DC-19-6, 6. PMCP-1018, 7. P. Vitthai, 8. P. Rakhumai, 9. P. Sonali, 10. PMCP-1005.





VARIABILITY IN BACTERIA

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Variability : Any change in the genotype of a bacterium or its phenotype is known as variation. There are four types of variability

1. Conjugation
2. Transformation
3. Transduction
4. Transposable elements

INTRODUCTION:

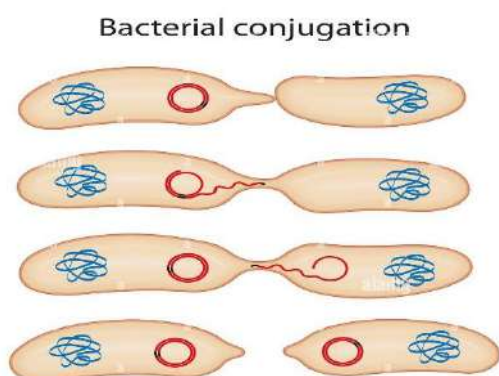
Bacteria reproduce by splitting in two via binary fission. Binary fission makes **clones**, or genetically identical copies, of the parent bacterium. Since the "child" bacteria are genetically identical to the parent, binary fission doesn't provide an opportunity for genetic recombination or genetic diversity (aside from the occasional random mutation). This contrasts with sexual reproduction. Still, genetic variation is key to the survival of a species, allowing groups to adapt to changes in their environment by natural selection. That's true for bacteria as well as plants and animals. So, it's not too surprising that prokaryotes can share genes by three other mechanisms: conjugation, transformation, and transduction.

1. In **transformation**, a bacterium takes up a piece of DNA floating in its environment.
2. In **transduction**, DNA is accidentally moved from one bacterium to another by a virus.
3. In **conjugation**, DNA is transferred between bacteria through a tube between cells.
4. **Transposable elements** are chunks of DNA that "jump" from one place to another. They can move bacterial genes that give bacteria antibiotic resistance or make them disease-causing.



CONJUGATION:

In conjugation, DNA is transferred from one bacterium to another. After the donor cell pulls itself close to the recipient using a structure called a pilus, DNA is transferred between cells. In most cases, this DNA is in the form of a plasmid. Donor cells typically act as donors because they have a chunk of DNA called the fertility factor (or F factor). This chunk of DNA codes for the proteins that make up the sex pilus. It also contains a special site where DNA transfer during conjugation begins. If the F factor is transferred during conjugation, the receiving cell turns into an F⁺ start superscript, plus, end superscript donor that can make its own pilus and transfer DNA to other cells. Here's one analogy: this process is sort of like how a vampire can turn other people into vampires by biting them.



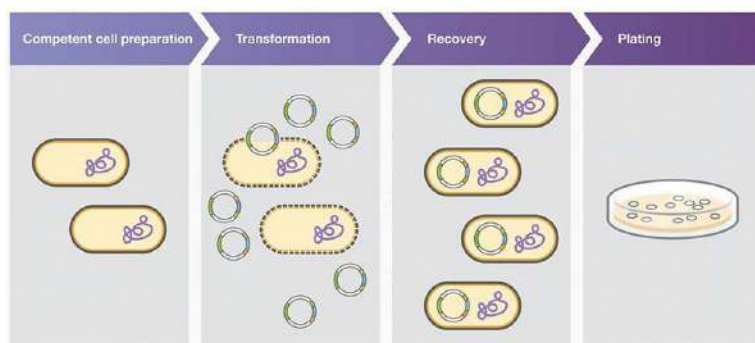
Bacterial conjugation 1st reported in *E. coli*

TRANSFORMATION:

In transformation, a bacterium takes in DNA from its environment, often DNA that's been shed by other bacteria. In a laboratory, the DNA may be introduced by scientists (see biotechnology article). If the DNA is in the form of a circular DNA called a plasmid, it can be copied in the receiving cell and passed on to its descendants. Why would this be important? Imagine that a harmless bacterium takes up DNA for a toxin gene from a pathogenic (disease-causing) species of bacterium. If the receiving cell incorporates the new DNA into its own chromosome (which can happen by a process called homologous recombination), it too may become pathogenic.



Bacterial Transformation



Reported 1st in *Pneumoniae*

Natural transformation:

In natural transformation, bacteria naturally can incorporate DNA from the environment directly.

Artificial transformation:

The competence of the host cell must be developed artificially through different techniques.

It has been demonstrated in several bacterial species, most notably in *E. coli*.

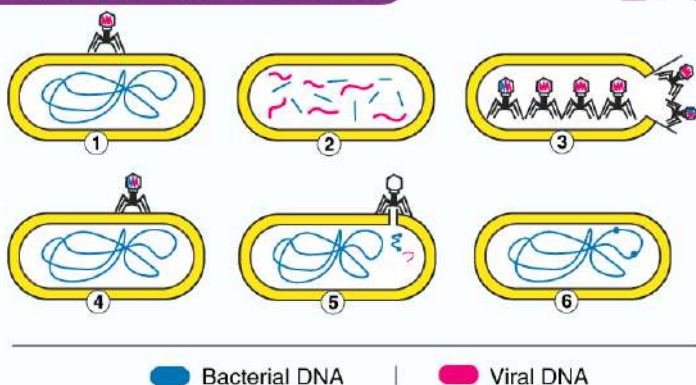
TRANSDUCTION:

In transduction, viruses that infect bacteria move short pieces of chromosomal DNA from one bacterium to another "by accident." Even bacteria can get a virus! The viruses that infect bacteria are called bacteriophages. Bacteriophages, like other viruses, are the pirates of the biological world—they commandeer a cell's resources and use them to make more bacteriophages. Sometimes, chunks of host cell DNA get caught inside the new bacteriophage as they are made. When one of these "defective" bacteriophages infect a cell, it transfers the DNA. Some bacteriophages chop the DNA of their host cell into pieces, making this transfer process more likely to start superscript. Archaea, the other group of prokaryotes besides bacteria, are not infected by bacteriophages but have their own viruses that move genetic material from one individual to another.



BACTERIAL TRANSDUCTION

BYJU'S
The Learning App



(Sources: BYJU'S)

Reported 1st in *Salmonella*

1.Generalized transduction:

1. It can occur by both lytic or lysogenic cycle.
2. Any random part of DNA gets packed in bacteriophages by mistake along with the viral genome.
3. It is done by virulent bacteriophages
4. It used to study linkage information, gene mapping, comparing genomes of two different bacteria, mutagenesis, etc.
5. **Example:** *E. coli* transduction by P1 phage.

2.Specialized transduction:

- Specialized transduction can occur only through the lysogenic cycle.
- The specific part of the bacterial DNA is packed into the virus.
- It is commonly used for isolation and insertion of genes.
- **Example:** *E. coli* transduction by λ phage.

TRANSPOSABLE ELEMENTS:

Transposable elements are also important in bacterial genetics. These chunks of DNA "jump" from one place to another within a genome, cutting and pasting themselves or inserting copies of themselves in new spots. Transposable elements are found in many organisms not just in



bacteria. In bacteria, transposable elements sometimes carry antibiotic resistance and pathogenicity genes (genes that make bacteria disease-causing). If one of these transposable elements 'jumps' from the chromosome into a plasmid, the genes it carries can be easily passed to other bacteria by transformation or conjugation. That means the genes can spread quickly through the population.

The variability in bacterial population can be determined by:

1. Pathogenic variability
2. Genetic variability

PATHOGENIC VARIABILITY:

1. Changes in the bacterial characters in response to environmental conditions.
2. Reversible-environmental cause is removed
3. Not heritable

Example: Flagella of *Salmonella* sp. which is absent in 0.1% phenol in culture medium.

2.GENETIC VARIABILITY

1. It is adjusted by the variability present in a given bacterial population.
2. It is studied using molecular markers like
3. RFLP-Restriction fragment length polymorphism
4. RAPD-Randomly amplified polymorphic DNA

CONCLUSION:

In bacteria, reproduction can be very fast, with a generation taking little more than a few minutes for some species. This short generation time, together with random mutations and the mechanisms of genetic recombination we saw in this article, allows bacteria (and other prokaryotes) to evolve very quickly. Rapid evolution means that bacteria can adapt to environmental changes, such as the introduction of an antibiotic very quickly. That's good for them—but bad for us, when we are the ones with the infection